FINAL REPORT: PART 1

EVALUATION OF ASPHALT PROPERTIES AND THEIR RELATIONSHIP TO PAVEMENT PERFORMANCE

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PRESENTATION AND EVALUATION OF DATA

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16. Abstract

This report is Part 1 of the final report for the research project titled "Evaluation of Asphalt Properties and Their Relationship to Pavement Performance." The overall objective of the research was to implement an analytical chemical procedure that could be used to characterize asphalt pavement materials. Results from the chemical analysis were subsequently used for the evaluation of pavement performance.

The chemical test procedure used corresponded to that developed by Corbett and Swarbrick. Fractional compositions were statistically related to a number of physical tests and asphalt temperature susceptibility indices.

This report also presents an evaluation of four different asphalt extraction/recovery procedures and an evaluation of a pressure oxygen bomb device used for asphalt laboratory aging.

The significant findings were:

- Fractional compositional analysis of asphalt showed that recovered asphalt is different than laboratory aged asphalt.
- Some physical properties of asphalt showed a good correlation to asphalt composition in the higher testing temperature range. At lower temperatures, however, relationships were more scattered.
- Different temperature susceptibility parameters have different relationships with chemical fractional composition.
- Different extraction/recovery procedures yielded different chemical fractional composition for the same asphalt.
- Pavement performance statistically relates to groups of asphalt properties.

Part 2 of this final report presents a microcomputer inventory for routine asphalt data.

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ABSTRACT

This report is Part 1 of the final report for the research project titled "Evaluation of Asphalt Properties and Their Relationship to Pavement Performance." The overall objective of the research was to implement an analytical chemical procedure that could be used to characterize asphalt pavement materials. Results from the chemical analysis were subsequently used for the evaluation of pavement performance.

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Significant findings include:

- Fractional compositional analysis of asphalt showed that recovered asphalt is different than laboratory aged asphalt.
- Some physical properties of asphalt showed a good correlation to asphalt composition in the higher testing temperature range. At lower temperatures, however, relationships are more scattered.
- Different temperature susceptibility parameters have different relationships with chemical fractional composition.
- Different extraction/recovery procedures yielded different chemical fractional composition for the same asphalt.
- Pavement performance statistically relates to groups of asphalt and asphalt mix properties, but the group of variables that may

enter the correlation depends on which parameters are used to evaluate pavement conditions.

Part 2 of this final report presents a microcomputer inventory for routine asphalt data.

1. INTRODUCTION

1.1 Scope

This report is Part 1 of the final report for the research project titled "Evaluation of Asphalt Properties and their Relationship to Pavement Performance." The overall objective of the research was to implement an analytical chemical procedure that could be used to characterize asphalt pavement materials. Results from the chemical analysis were subsequently used for the evaluation of pavement performance.

A detailed description of the research project was presented in an interim report (1), which included the following:

a) Literature review on asphalt chemistry and on test methods employed for chemical composition analysis.

b) Description of the research program and laboratory research work.

c) A detailed analysis and recommendations for the Corbett-Swarbrick chemical testing procedure (2), also ASTM-D4124. This test was the final test adopted for all the chemical analysis performed in the present research.

d) A computer inventory for routine asphalt data developed for a microcomputer.

1.2 Objectives

The objectives of this part of the final report are to:

a) Present laboratory testing results of asphalt pavement materials used in the research project. This includes results from tests on physical properties and chemical composition, as well as results from mathematical calculation of various property indices.

b) Evaluate possible relationships between:
   - physical properties and chemical composition and,
   - property indices and chemical composition

c) Evaluate the results obtained on recovered asphalt samples from four different extraction procedures.

d) Evaluate the results obtained on Fraass samples aged on Pressure Oxygen Bomb (POB) and its relationship to the Rolling Thin Film Oven Test (RTFO).

e) Analyze pavement performance as related to asphalt chemical composition.

A second and separate part of this final report presents a microcomputer inventory for routine asphalt data.

1.3 Organization of This Report

The results of the laboratory testing are presented in Chapter 2. The analysis and discussion of results (objectives b, c, and d above) are given in Chapter 3. The relationship of asphalt composition to pavement performance is discussed in Chapter 4. Conclusions and Recommendations are given in Chapter 5. Finally, a summary of all major findings is presented in Chapter 6.

2. REVIEW OF THE RESEARCH PROGRAM AND RESULTS

The research program was organized in five different parts. Each part is described briefly in this chapter.

2.1 Project Selection

Eight different highway projects throughout Oregon were selected for the study. These projects were chosen to represent a range of performance and highway environments. Figure 2.1, shows the approximate location of the projects and Table 2.1 a general description of the present conditions of the highways segments under study.

2.2 Core Sampling

Core samples were taken from the travel lanes on each of the eight projects. Also, core samples were taken from the shoulders in Project-5 and Project-7 (locations 5s and 7s, respectively in Table 2.2). At Project-3, a city street with no shoulders, core samples were also taken from a location away from the traffic path (location 3a in Table 2.2).

Core samples were cut in two halves; a top layer of approximately 1.5 to 2 inches and a bottom layer ranging from 2 to 4 inches. Separate testing was performed on each of the two layers. The reason for separating a top and bottom layer was to differentiate the environmental effects between the exposed and unexposed part of the pavement.

Table 2.2 presents the following information obtained from the top layers of the core sampling: thickness, maximum specific gravity, air voids, asphalt cement content, asphalt supplier and asphalt type, mix type, resilient modulus and fatigue life for 100 microstrains. This information was taken from reference (3) which was for a parallel research study on asphalt mixture properties which used the same eight projects chosen for this study.

2.3 Implementation of the Corbett-Swarbrick Procedure

This part of the project was reported extensively in reference (1). The Corbett-Swarbrick procedure (current ASTM-D4124) was submitted for revision by the ASTM committee D04.47 and a new small scale test was proposed. Although the proposed procedure is not yet an official standard, it was decided to use it in this study as the laboratory test for the evaluation of asphalt composition.

2.4 Laboratory Testing Program

Figure 2.2 summarizes the laboratory testing program. This program does not include the Rostler analysis, which was originally considered as a candidate for asphalt composition analysis for this study (1). The Corbett-Swarbrick procedure was considered to be the only analysis procedure necessary following a review of both methods.

The laboratory test results for all eight projects are presented in three major groups.

2.4.1 Asphalt Physical Properties of Original Samples and After Rolling Thin Film Oven Test (RTFO)

a) Asphalt Original Properties: asphalt original physical properties were available from date of construction. Nevertheless, since the data was not complete, asphalt physical properties were measured again using original asphalt that had been stored in sealed cans. The repetition of the physical tests on asphalt samples served a second purpose which was to determine whether the stored asphalt did undergo changes during the storage period.

b) Asphalt after RTFO: the stored asphalt was artificially aged in the RTFO and tested for physical properties. As above, RTFO data was available from date of construction but was also incomplete.

Table 2.3 shows the results obtained for original asphalts and after RTFO together with the results already available from date of construction.

2.4.2 Physical Properties from Core Recovered Asphalt

Asphalt samples were extracted and recovered separately from the top and bottom layer of each core. The current extraction and recovery procedure used by Oregon State Highway Division (OSHD) was used to obtain asphalt samples from cores in all eight projects (extraction-recovery procedure Method-A) (4). Experimentally, three other methods were also used to extract and recover asphalt from projects 3, 3a, 5, and 7. Figure 2.3 shows the general scheme for the extraction and recovery procedures used.

Table 2.4 shows physical test results for asphalt samples obtained using Method-A for all eight projects. Table 2.5 shows physical test results for projects 3, 3a, 5 and 7, using all four methods of asphalt extraction-recovery. Tables 2.4 and 2.5 have some missing values which correspond to samples that were either initially contaminated or unavailable for experimental laboratory procedures.

2.4.3 Asphalt Chemical Fractionation Test Results

The Corbett-Swarbrick chemical analysis yields four distinct fractions: asphaltenes, saturates, naphthene-aromatics, and polar-aromatics. The procedure is summarized in Figure 2.4.

Table 2.6 shows the asphalt chemical composition for original samples and after RTFO. Table 2.7 shows chemical composition for recovered asphalt in all eight projects using Method-A. Table 2.8 shows asphalt chemical composition of projects 3, 5 and 7 after having been recovered by using all four methods of recovery-extraction.

All chemical test results shown in Tables 2.6 through 2.8 correspond to the average of two separate and independent tests. Table 2.9 shows the standard deviation and range for each fraction obtained during the present research together with the proposed criteria given by ASTM-D4124.

2.4.4 Fraass Test Results Before and After Pressure Oxygen Bomb Aging Test (POB)

This part of the research involved the use of the Fraass samples, which were aged in a POB device for 2 and 5 days and subsequently tested for Fraass Breaking Point and chemical composition analysis. The purpose of this part of the research was to assess the chemical changes undergone by the asphalt samples after being subjected to the POB aging test. The chemical composition undergone during POB tests were compared with changes in Fraass temperature and to the changes undergone by asphalt after RTFO. Only projects 3, 5, and 7 were used as a preliminary part of this research.

The use of the Fraass test sample for aging studies and its advantages are reported in references (5) and (6). The characteristics of the POB device were reported in reference (3) and the aging conditions of the test could be summarized as follow: 100 psi Oxygen Pressure, 60°C (140°F) and, 2 and 5 days aging.

Since the amount of materials obtained from the aged Fraass sample is relatively small, only one physical property was measured (Fraass Brittle

Point) and the chemical analysis was run only once. Table 2.10 shows the results of Fraass test and chemical compositional analysis for original, POB (2 and 5 days), and RTFO.

2.5 Asphalt Property Indices

In order to correlate chemical composition analysis with temperature susceptibility, the following indices were calculated as follows:

a) Penetration Index (PI) (7, 8):

$$PI = (20-50A)/(1 + 50A) \tag{2.1}$$

where:

$A = (\log P(T1) - \log P(T2))/(T1-T2)$

$T1 = 25°C$

$T2 = 60°C$

$P(T1)$ = Penetration measured at 25°C

$P(T2)$ = Penetration calculated at 60°C using the following relationship

$$P(T2) = \left(\frac{-5.42 \log (V60/13000)}{8.5 + \log (V60/13000)}\right) - \log 800 \tag{2.2}$$

where:

V60 = Absolute Viscosity

(Large negative values of PI indicates greater temperature susceptibility. Typical asphalts have values between +2 and -2).

b) Viscosity Temperature Susceptibility (VTS) (9):

$$VTS = (\log \log V(T2) - \log \log V(T1))/(\log T1 - \log T2) \quad (2.3)$$

T1 = 333 K (60°C)

T2 = 408 K (135°C)

V(T1) = Absolute viscosity at 60°C, in poises

V(T2) = Kinematic viscosity at 135°C, in poises where:

$$1 \text{ cStoke} * (.95/100) \approx 1 \text{ poise}$$

(greater VTS indicates greater temperature susceptibility)

c) Penetration Viscosity Number (PVN) (10):

$$PVN = \left(\frac{4.258-0.7967 \log P25 - \log KVis}{0.7951-0.1858 \log P25}\right) * (-1.5) \quad (2.4)$$

where:

P25 = Penetration at 25°C

KVis = Kinematic Viscosity at 135°C, cStoke

(Lower PVN indicates greater temperature susceptibility)

d) Penetration Ratio (PR):

$$PR = \frac{\text{Pen @ 4°C, 200 g, 60 sec}}{\text{Pen @ 25°C, 100 g, 5 sec}} \quad (2.5)$$

(Lower PR indicates greater temperature susceptibility.)

Table 2.11 presents the results of the above indices for original and RTFO samples and Table 2.12 for recovered asphalt in all eight projects using Method A. Table 2.13 presents results for samples 3, 5 and 7 using all four recovery procedures.

Table 2.1: Project Description

Proj. #	Name and Location	Year of Construc.	ADT for 1985 (1)	Trucks % (1)	Rating Cond. for 1985 (2)	General Observations
1	Grande Ronde - Wallace Bridge, St.Hwy-18	1980	9500	12.5	very good	No significant cracking ravelling or shoving
2	Dayton - Lafayette Jct., St.Hwy-18	1980	4050	12.3	very good	No significant cracking ravelling or shoving
3	Idlywood Street, City of Salem	1974	n/a	n/a	good	No significant cracking ravelling or shoving
4	Elk River - North Port Orford, U.S.Hwy-101	1976	5100	13.9	fair	n/a
5	Plain View Rd. - Deschutes River, U.S.Hwy- 20	1980	3550	13.3	fair	5% raveled 5% cracked
6	Klamath Falls-Green Spring Jct., U.S.Hwy-97	1981	9600	36.8	good/fair	5% raveled 5% cracked
7	Arnold Ice Caves - Horse Ridge, U.S.Hwy- 20	1973	1350	14.8	fair	25% shoved 10% cracking
8	S. Fork Malheur - New Princeton, St.Hwy- 78	1974	190	5.0	poor	95% cracks, 5% spalling 5% ravelling

(1) OSHD, Official Publication #86-1, July 1986
(2) OSHD, Unclassified Publication from the Pavement Management Unit, February 1985

Table 2.2: Cores and Mix Properties.

Proj. (#)	Thickness (in)	Max. Sp. Grav.	Air Voids	A/c %	Asphalt Suplier	Mix Type	Mr (ksi)	Nf (1)
1	1.72	2.476	11.1	5.0	Chevron AR4000w	B-mix	862.00	80350
2	2.44	2.580	8.5	5.7	Chevron AR4000w	B-mix	1103.19	10005
3	1.91	2.459	11.8	5.9	Chevron AR4000	B-mix	771.87	276292
3a	-	-	-	-		-	-	-
4	1.44	2.421	5.0	7.0	Douglas AR4000	B-mix	281.94	-
5	1.41	2.497	8.3	5.8	Chevron AR4000	B-mix	568.97	42480
5s	1.83	2.484	9.0	5.6			703.78	129064
6	2.49	2.535	6.1	5.2	Witco AR2000	B-mix	1031.63	4112
7	1.55	2.444	4.3	6.7	Douglas 120/150p	B-mix	243.30	295241
7s	1.92	2.434	4.3	6.9			186.30	1876282
8	1.44	2.158	8.7	7.6	Shell AR2000	C-mix	621.94	87662

(1) Nf, calculated for 100 microstrains

a = Away from traffic path
s = Shoulder

Table 2.3: Physical Properties of Original Samples and after Rolling Thin Film Oven Test.

Sample	Data Available from Date of Construction				Data Measured During 1985			
	Pen-4	Pen-25	Vis-60 (poises)	KVis-135 (cStokes)	Pen-4	Pen-25	Vis-60 (poises)	KVis-135 (cStokes)
1-Orig.	18	73	1552	352	23	72	1783	364
2-Orig.	18	73	1552	352	26	77	1613	352
3-Orig.	50	139	-	-	47	128	1169	353
4-Orig.	49	134	1110	340	48	128	1124	335
5-Orig.	20	80	1504	368	22	74	1577	345
6-Orig.	17	85	1052	201	17	88	1059	190
7-Orig.	46	140	762	236	31	128	768	244
8-Orig.	25	100	-	-	15	84	992	190
1-RTFO	-	39	4191	572	16	43	4216	545
2-RTFO	-	39	4191	572	16	44	3960	526
3-RTFO	-	66	4306	608	30	60	4592	665
4-RTFO	-	65	4344	633	32	65	4193	619
5-RTFO	-	46	3858	494	20	52	3858	513
6-RTFO	-	66	1876	255	15	66	1678	247
7-RTFO	-	-	2164	-	30	66	2524	393
8-RTFO	-	60	2051	260	14	54	2068	267

Table 2.4: Physical Test Results of Recovered Asphalt Using Method-A. Projects 1 to 8.

Sample #	Pen-4	Pen-25	Vis-60 (poises)	KVis-135 (cStokes)
1-Top	2	11	59284	1933
2-Top	4	15	13299	572
3-Top	9	10	225129	3952
3a-Top	6	12	100000	3802
4-Top	26	51	3403	399
5-Top	14	22	13584	885
5s-Top	12	26	11755	853
6-Top	11	27	4440	330
7-Top	32	63	5524	745
7s-Top	31	80	3611	616
8-Top	6	11	25104	665
1-Base	5	12	74152	1953
2-Base	6	14	12571	569
3-Base	6	16	106328	2798
3a-Base	9	22	45564	1916
4-Base	-	51	3194	401
5-Base	*	*	*	*
5s-Base	15	47	4360	531
6-Base	-	42	2565	268
7-Base	-	80	1769	466
7s-Base	-	114	1752	465
8-Base	13	45	2845	318

* Sample Contaminated

Table 2.5: Physical Test Results of Asphalts from Projects 3, 5 & 7 Obtained Using all four Methods of Extraction/Recovery.

Sample #	Method	Pen-4	Pen-25	Vis-60 (poises)	KVis-135 (cStokes)
3-Top	A	2	11	59284	1933
	B	4	11	160000	3472
	C	134	140	3213	493
	D	14	21	46179	1969
3a-Top	A	6	12	100000	3802
	B	5	10	185999	6509
	C	16	23	56593	2242
	D	7	16	44869	2872
5-Top	A	14	22	13584	885
	B	3	21	17253	896
	C	8	20	15284	985
	D	32	80	19444	451
7-Top	A	32	63	5524	745
	B	-	-	-	-
	C	22	54	6392	764
	D	22	48	7507	819
3-Base	A	6	16	106328	2798
	B	6	16	85619	2413
	C	16	123	1228	407
	D	6	15	102308	2187
3a-Base	A	9	22	45564	1916
	B	6	20	42937	1926
	C	18	43	18040	1222
	D	10	22	10799	1797
5-Base	A	*	*	*	*
	B	9	36	7630	717
	C	12	36	6681	657
	D	11	32	8036	718
7-Base	A	-	80	1769	466
	B	38	89	3060	545
	C	27	80	3002	560
	D	-	-	-	-

* Sample Contaminated

Table 2.6: Chemical Composition of Original Samples and after Rolling Thin Film Oven Test.

Sample	Asph. %	Sat. %	N-Arom. %	P-Arom. %	Total %
Orig.-1	16.5	9.5	26.2	47.0	99.2
Orig.-2	15.7	9.1	26.9	46.6	98.3
Orig.-3	22.7	8.4	24.5	43.3	98.9
Orig.-4	20.2	9.1	24.9	43.8	98.0
Orig.-5	16.6	9.3	26.5	46.9	99.3
Orig.-6	6.0	11.6	33.1	48.1	98.8
Orig.-7	17.0	9.6	27.9	45.3	99.8
Orig.-8	6.9	10.9	32.4	48.3	98.5
RTFO-1	21.4	7.9	25.5	43.7	98.5
RTFO-2	20.5	7.8	25.2	45.1	98.6
RTFO-3	27.8	7.1	22.3	41.8	99.0
RTFO-4	24.5	8.1	22.8	43.9	99.3
RTFO-5	21.8	8.2	25.0	43.8	98.8
RTFO-6	11.2	10.9	29.7	46.9	98.7
RTFO-7	21.3	9.2	24.6	44.5	99.6
RTFO-8	14.2	10.3	27.1	47.0	98.6

Table 2.7: Fractional Composition of Recovered Asphalt using Method-A. Projects 1 to 8

Sample	Asph. %	Sat. %	N-Arom. %	P-Arom. %	Total %
1-Top	32.2	7.1	20.9	39.3	99.5
2-Top	20.0	9.7	22.5	45.6	97.8
3-Top	36.8	5.6	20.0	36.4	98.8
3a-Top	39.1	6.1	19.1	35.5	99.8
4-Top	23.4	9.6	21.8	43.6	98.4
5-Top	25.4	8.0	22.2	42.2	97.8
5s-Top	28.4	7.6	22.4	40.4	98.8
6-Top	19.7	10.6	23.3	44.4	98.0
7-Top	28.5	8.4	20.7	41.8	99.4
7s-Top	28.8	8.3	23.2	39.7	100.0
8-Top	24.0	9.6	21.9	44.0	99.5
1-Base	32.4	6.1	20.8	39.8	99.1
2-Base	20.8	10.0	22.5	45.4	98.7
3-Base	36.1	5.8	20.1	37.2	99.2
3a-Base	34.3	6.9	20.2	38.3	99.7
4-Base	24.0	9.6	21.9	43.4	98.9
5-Base	-	-	-	-	-
5s-Base	-	-	-	-	-
6-Base	13.8	11.3	24.5	49.1	98.7
7-Base	25.2	8.6	22.2	43.1	99.1
7s-Base	24.2	7.9	24.0	43.9	100.0
8-Base	16.5	10.2	24.8	46.6	98.1

Table 2.8: Fractional Composition of Asphalt Obtained Using all Four Extraction/Recovery Methods. Projects 3, 5 & 7.

Sample #	Method	Asph. %	Sat. %	N-Arom. %	P-Arom. %	Total %
3-Top	A	36.8	5.6	20.0	36.4	98.8
	B	37.6	6.3	20.0	35.3	99.2
	C	33.7	7.0	18.8	39.5	99.0
	D	38.8	6.6	17.4	35.7	98.5
3a-Top	A	39.1	6.1	19.1	35.5	99.8
	B	39.6	6.2	17.4	36.3	99.5
	C	38.1	6.5	16.6	36.7	97.9
	D	35.4	6.7	18.7	38.4	99.2
5-Top	A	25.4	8.0	22.2	42.2	97.8
	B	27.4	6.6	24.3	41.5	99.8
	C	25.1	7.2	21.5	44.9	98.7
	D	27.3	7.4	20.0	43.7	98.4
7-Top	A	28.5	8.4	20.7	41.8	99.4
	B	30.9	7.9	20.4	40.0	99.2
	C	30.3	7.6	21.9	39.2	99.0
	D	31.4	7.6	19.7	39.8	98.5
3-Base	A	36.1	5.8	20.1	37.2	99.2
	B	39.3	6.1	19.8	34.6	99.8
	C	31.5	7.0	19.6	40.1	98.2
	D	37.2	6.4	17.1	38.0	98.7
3a-Base	A	34.3	6.9	20.2	38.3	99.7
	B	34.1	7.3	19.3	38.8	99.5
	C	35.7	6.2	17.4	38.5	97.8
	D	34.2	6.1	19.4	38.7	98.4
5-Base	A	-	-	-	-	-
	B	27.7	6.9	23.6	41.6	99.8
	C	24.9	7.3	22.6	43.7	98.5
	D	27.1	7.9	21.2	41.9	98.1
7-Base	A	25.2	8.6	22.2	43.1	99.1
	B	29.3	7.5	22.0	39.6	98.4
	C	29.7	7.2	23.4	38.7	99.0
	D	-	-	-	-	-

Table 2.9: Repeatability of Results for Individual Chemical Fractions

Fractions	Actual Testing		ASTM Criteria			
	Single Operator		Single Operator		Multi Laboratory Precision	
	Standard Deviation	Range	Standard Deviation	Range	Standard Deviation	Range
Asphaltenes	0.40	1.1	0.32	0.9	0.95	2.7
Saturates	0.31	1.1	0.44	1.2	0.70	1.9
N-Aromatics	0.88	2.1	1.03	2.9	2.26	6.4
P-Aromatics	0.53	1.6	0.78	2.2	2.37	6.7

Table 2.10: Fraass Test Results and Fractional Composition of Asphalt Before and After Aging Tests, Pressure Oxygen Bomb, and Rolling Thin Film Test.

Sample	Fraass (C)	Asph. %	Sat. %	N-Arom. %	P-Arom. %	Total %
3-Original	-17.4	22.7	8.4	24.5	43.3	98.9
3-RTFO	-12.1 *	27.8	7.1	22.3	41.8	99.0
3-POB, 2 days	-14.8	27.2	7.7	23.6	39.8	98.3
3-POB, 5 days	-11.7	29.0	7.2	23.4	39.4	99.0
5-Original	-16.6	16.6	9.3	26.5	46.9	99.3
5-RTFO	-10.0 *	21.8	8.2	25.0	43.8	98.8
5-POB, 2 days	-7.1	22.4	8.0	25.8	42.3	98.5
5-POB, 5 days	-5.9	24.3	7.6	25.1	40.8	97.8
7-Original	-17.7	17.0	9.6	27.9	45.3	99.8
7-RTFO	-14.2 *	21.3	9.2	24.6	44.5	99.6
7-POB, 2 days	-13.3	18.4	10.1	27.4	43.9	99.8
7-POB, 5 days	-11.2	18.9	9.8	26.8	44.1	99.6

* Value Estimated from Bituminous Test Data Chart

Table 2.11: Property Indices of Original Asphalt Samples and after Rolling Thin Film Oven Test.

Sample	P.I.	V.T.S.	P.V.N.	P.R.
1-Orig.	-1.127	3.567	-0.684	0.319
2-Orig.	-1.115	3.565	-0.656	0.338
3-Orig.	-0.694	3.429	-0.014	0.367
4-Orig.	-0.752	3.457	-0.075	0.375
5-Orig.	-1.224	3.568	-0.733	0.297
6-Orig.	-1.446	3.941	-1.465	0.193
7-Orig.	-1.292	3.571	-0.616	0.242
8-Orig.	-1.597	3.913	-1.514	0.179
1-RTFO	-0.872	3.588	-0.671	0.372
2-RTFO	-0.910	3.539	-0.696	0.364
3-RTFO	-0.138	3.466	-0.007	0.500
4-RTFO	-0.107	3.486	-0.012	0.492
5-RTFO	-0.694	3.602	-0.549	0.385
6-RTFO	-1.311	3.891	-1.360	0.227
7-RTFO	-0.785	3.653	-0.669	0.455
8-RTFO	-1.367	3.906	-1.442	0.259

P.I. (Pen 25 C & Abs. Vis. 60 C)
V.T.S. (Abs. Vis. 60 C & Kin. Vis. 135 C)
P.V.N. (Pen 25 C & Kin. Vis. 135 C)
P.R. (Pen 4 C & Pen 25 C)

Table 2.12: Property Indices of Recovered Asphalt Using Method-A. Projects 1 to 8.

SAMPLE	P.I.	V.T.S.	P.V.N.	P.R.
1-Top	-0.330	3.594	-0.426	0.182
2-Top	-1.325	3.977	-1.550	0.267
3-Top	+0.973	3.550	+0.271	0.900
3a-Top	-0.436	3.332	+0.410	0.500
4-Top	-0.846	3.757	-0.928	0.510
5-Top	-0.661	3.645	-0.706	0.636
5s-Top	-0.524	3.622	-0.592	0.462
6-Top	-1.554	4.019	-0.100	0.407
7-Top	+0.241	3.450	+0.222	0.508
7s-Top	+0.098	3.433	+0.253	0.387
8-Top	-1.196	4.068	-1.607	0.545
1-Base	+0.091	3.657	-0.337	0.417
2-Base	-1.485	3.952	-1.607	0.429
3-Base	+1.209	3.538	+0.356	0.375
3a-Base	-0.857	3.516	+0.243	0.409
4-Base	-0.926	3.729	-0.920	-
5-Base	-	-	-	-
5s-Base	-0.673	3.621	-1.086	0.319
6-Base	-1.498	3.988	-1.667	-
7-Base	-0.929	3.371	-0.178	-
7s-Base	-0.298	3.369	+0.307	-
8-Base	-1.272	3.879	-1.369	0.289

P.I. (Pen 25 C & Abs. Vis. 60 C)
V.T.S. (Abs. Vis. 60 C & Kin. Vis. 135 C)
P.V.N. (Pen. 25 C & Kin. Vis. 135 C)
P.R. (Pen 4 C & Pen 25 C)

Table 2.13: Property Indices of Asphalt Samples from Projects 3, 5 & 7 Using all Four Extraction Procedures.

Sample	Method	P.I.	V.T.S.	P.V.N.	P.R.
3-Top	A	+0.937	3.550	+0.271	0.900
	B	+0.794	3.528	+0.222	0.364
	C	+1.207	3.563	+0.728	0.957
	D	+0.763	3.502	+0.226	0.667
3a-Top	A	+0.436	3.332	+0.410	0.500
	B	+0.745	3.205	+0.817	0.500
	C	+1.275	3.483	+0.486	0.696
	D	+0.114	3.252	-0.387	0.438
5-Top	A	-0.661	3.645	-0.706	0.636
	B	-1.801	3.558	-0.734	0.143
	C	-0.698	3.609	-0.665	.4.4
	D	-0.801	3.435	-0.228	0.508
7-Top	A	+0.241	3.450	-0.222	-
	B	-	-	-	-
	C	+0.122	3.484	-0.063	0.407
	D	+0.104	3.491	-0.018	0.458
3-Base	A	+1.209	3.538	+0.356	0.375
	B	+0.921	3.560	+0.138	0.375
	C	+0.692	3.330	+0.197	0.130
	D	+0.994	3.683	+0.003	0.400
3a-Base	A	+0.857	3.517	+0.243	0.409
	B	+0.552	3.493	+0.147	0.300
	C	-1.168	3.513	+0.439	0.419
	D	-0.921	3.072	+0.164	0.455
5-Base	A	-	-	-	-
	B	-0.470	3.719	-0.487	0.250
	C	-0.615	3.614	-0.603	0.333
	D	-0.602	3.614	-0.607	0.344
7-Base	A	-0.929	3.371	-0.178	-
	B	+0.066	3.460	+0.209	0.427
	C	+0.104	3.491	+0.106	0.338
	D	-	-	-	-

P.I. (Pen 25 C & Abs. Vis. 60 C)
V.T.S. (Abs. Vis. 60 C & Kin. Vis. 135 C)
P.V.N. (Pen. 25 C & Kin. Vis. 135 C)
P.R. (Pen 4 C & Pen 25 C)

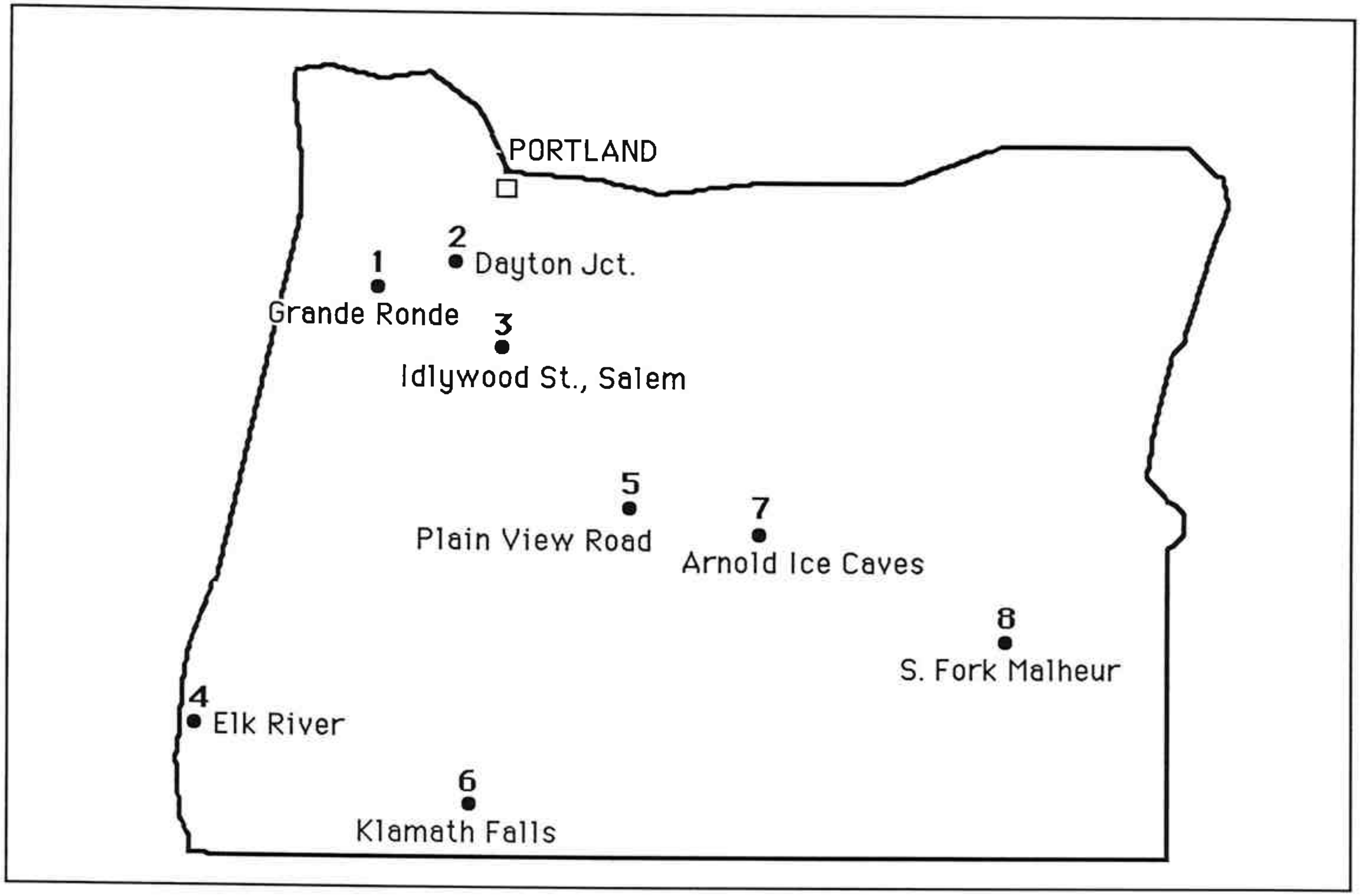

Figure 2.1: Project Locations

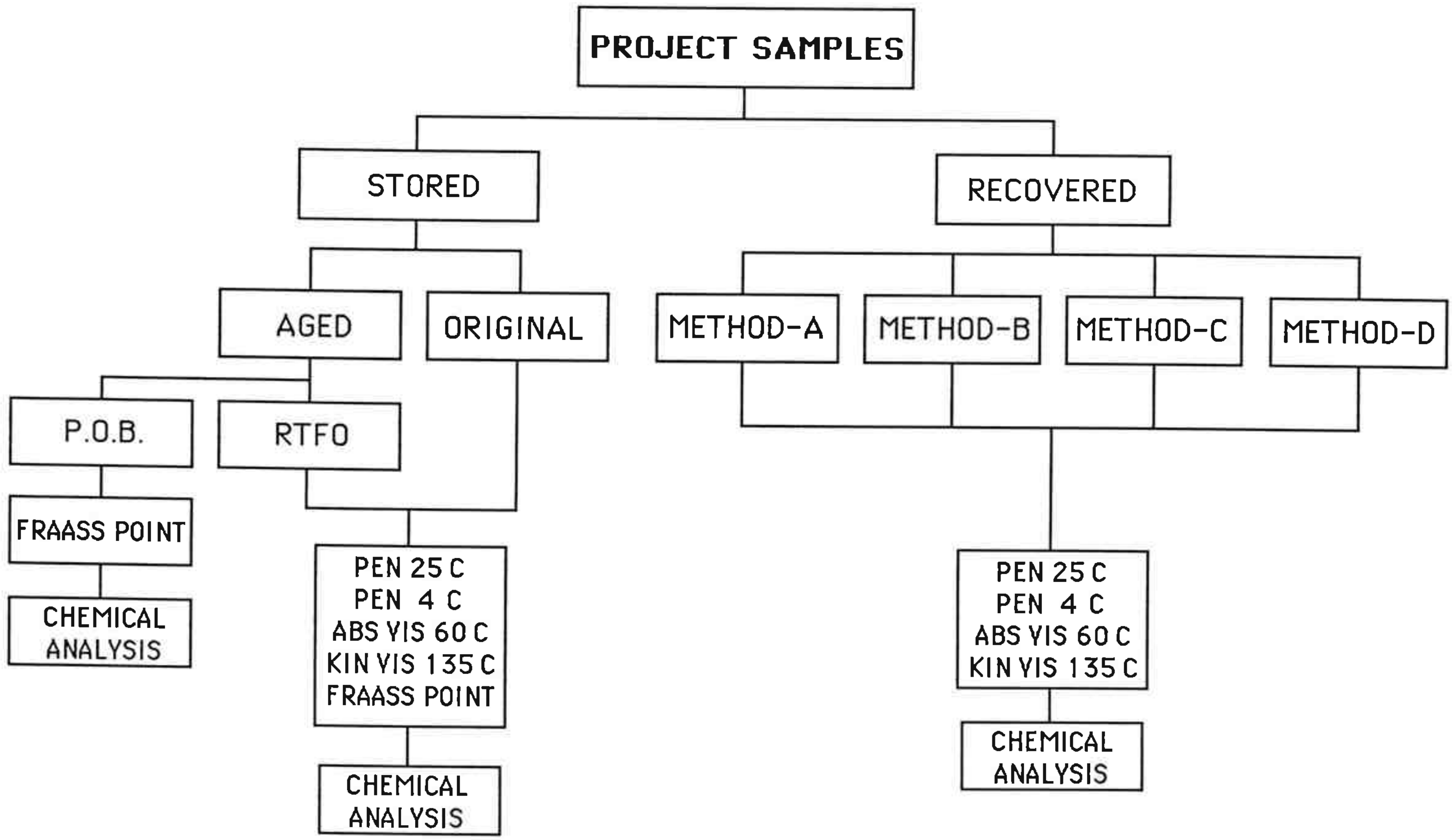

Figure 2.2: Laboratory Research Program

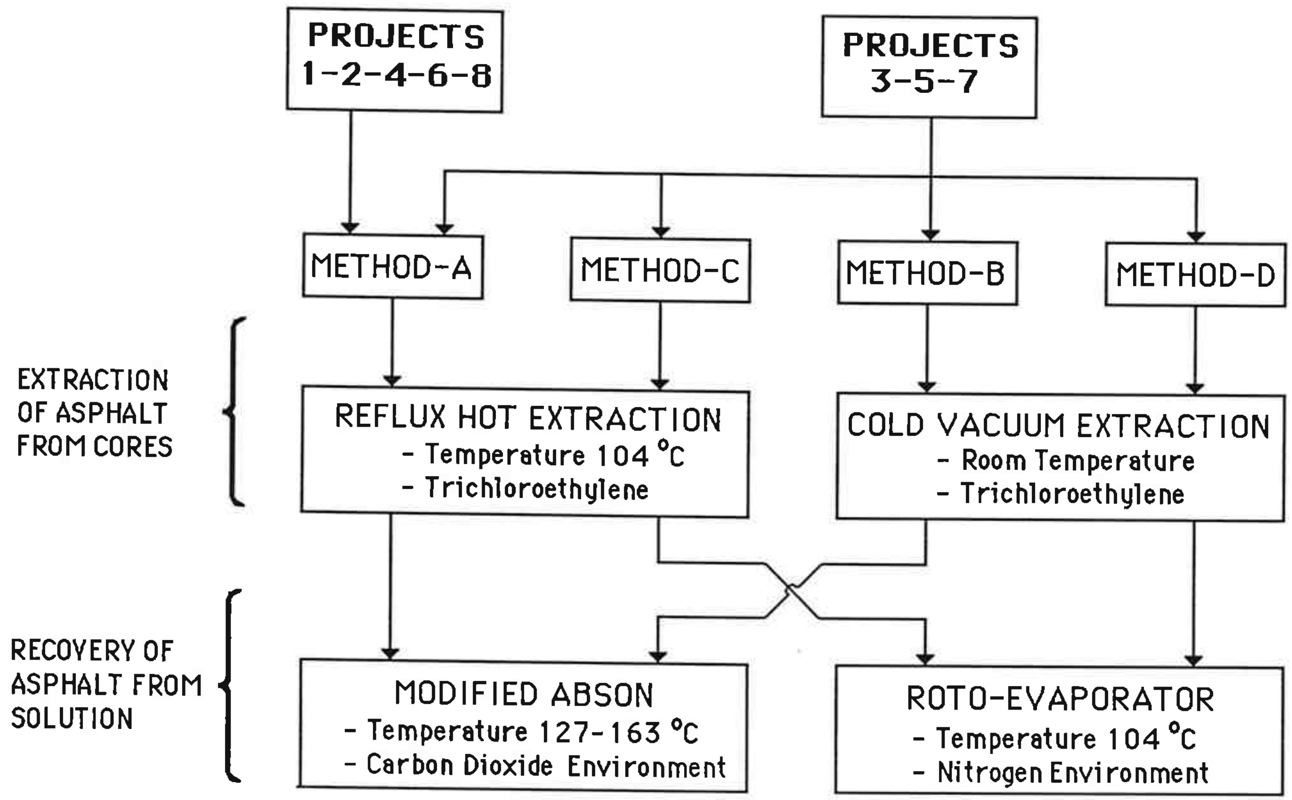

Figure 2.3: Asphalt Extraction/Recovery Procedures

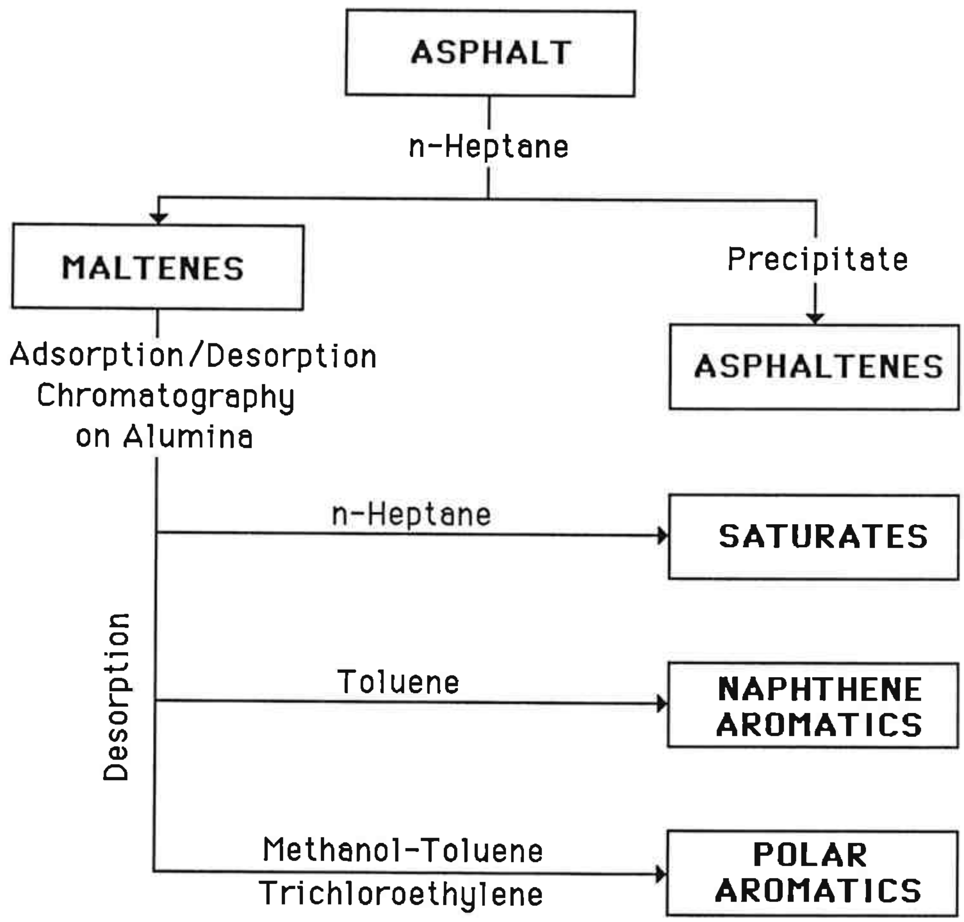

Figure 2.4: Adsorption / Desorption Chromatography by Corbett - Swarbrick Procedure, ASTM D-4124

3. ANALYSIS OF THE RESULTS AND DISCUSSION

3.1 Data from Date of Construction versus Data from Stored Asphalt

Table 2.3 shows results of physical properties of original samples before and after the storage period. Some minor variations of physical properties were noticed. These variations are attributed to variation in testing over a period of five to eleven years rather than aging which may have occurred during the storage period. By looking at changes in penetration at 25°C, absolute viscosity and kinematic viscosity, it can be observed that there is no general trend in the changes undergone by each asphalt sample; i.e., some tests indicate that the material has hardened while others show that the material has become softer or not changed at all. The average variation was around 5% in both directions (hardening or softening).

3.2 Relationship Between Chemical Fractions

Six possible relationships between the four chemical fractions obtained through the Corbett-Swarbrick analysis were studied. Figures 3.1 through 3.6 show these relationships and include results from original samples, RTFO, and recovered asphalt using Method-A.

Initially, the relationship analysis was going to be studied, using only results of original samples. Some trends were noticed using results from the chemical analysis performed on original samples, but these were insufficient to extrapolate beyond the range shown by the asphalt type used.

To increase the range variation, the results from asphalt samples after RTFO aging test were included. With the above increase in fraction range, more clear trends were observed. The inclusion of results from samples after RTFO may be considered as adding asphalt in a higher range of consistency, since the RTFO test involves the use of heat and oxygen to age the asphalt and this is one technique used in refinery to produce some type of high consistency asphalt. Plotting the results of original samples together with the RTFO results, the range variation of chemical fractions was increased and the trends found when plotting original results alone were improved.

Results from recovered asphalt using Method-A, cover an even higher range of asphalt fraction proportions. These results were also added to the analysis but as seen from Figures 3.1 through 3.6, a different trend is observed for the recovered asphalt as compared with the original plus RTFO samples.

The fact that recovered asphalt does not show the same relationships observed for original plus RTFO samples may be explained as follows:

a) Recovered asphalt, after going through the extraction and recovery procedure may be chemically altered and no longer represents the in-place asphalt.

b) The RTFO accelerated aging procedure may not duplicate the chemical changes undergone by asphalt under natural weathering.

Based only on the results of this study, it is difficult to differentiate how the above two factors are contributing to the differences in relationships observed in Figures 3.1 through 3.10.

For either the original plus RTFO or recovered asphalt, relatively good linear relationships were observed between any two chemical fractions. Statistical relationships were developed in terms of linear equations in which the proportion of one component was expressed as a function of the other (Table 3.1).

From Table 3.1 it can be observed that the relatively good relationships (R-squared greater than 0.8) were those where the asphaltene fraction is the independent variable and the saturates, naphthene-aromatics and polar-aromatics were the dependent variables, respectively. Since the asphaltene fraction is the first component obtained during the chemical separation (prior to the chromatographic analysis) knowing the percentage of asphaltenes the proportion of the other three fractions may be estimated.

The relationships given in Table 3.1 were obtained based on a relative small population, i.e., the asphalt samples obtained from the eight projects were from five different suppliers in which three of the projects constructed in 1980 used the same supplier (Chevron). Considering that asphalt may be very different depending upon their origin, supplier, and year of production, the population of asphalt used should be considered small. Nevertheless, by combining results of original samples with the RTFO samples, it was possible to cover almost the entire range variation on the percentage of all four generic fractions, although this does not imply that all types of asphalts were represented.

The relationships obtained for recovered asphalt may be considered to represent a larger sample since the recovered asphalt represents samples aged in twenty-two different environment and traffic conditions, i.e., samples from eight different environments, samples from the road surface and bottom layer, samples from travel lanes and samples from shoulders.

3.3 Comparison with Other Studies - Relationship Between Chemical Fractions

To find out whether the results of the relationships obtained (Table 3.1) can be extrapolated to other asphalts, results from the Michigan Road Test (11) were analyzed. The Michigan Road Test was the first large-scale program where the Corbett-Swarbrick analysis was used to chemically characterize the asphalt.

Table 3.2 summarizes the results and shows comparisons with the actual results given in reference (11). The values shown in Table 3.2 are for saturates, n-aromatics, and p-aromatics based on the actual asphaltene content as measured in the Michigan Road Test. The following paragraphs present the major trends indicated in Table 3.2, which are also depicted in Figures 3.7, 3.8, and 3.9:

a) As seen in Table 3.2, there were some important deviations in which the asphalt samples do not fit the linear regression established. Figures 3.7 through 3.9 show that, although results from the Michigan Road Test deviate from the statistical relationships given in Table 3.1, the general trends established in the present research are still valid. There could be several reasons for the above deviation; one of these may be that multilaboratory precision range is very high (ASTM-D4124), these values are given in Table 2.9. A second reason for some of the large deviations could be that some asphalts may exhibit inexplicable anomalies during repeated trials of the test, this was true when using original samples from Project-7 and also, similar cases have been reported in the literature (12).

b) Recovered asphalt data from reference (11) are closer to the trends given by the linear equations than the original asphalt data. However, some deviations were expected since the Abson asphalt recovery procedure used in the present research is a modified version of the original ASTM procedure in the Michigan road test.

One of the objectives of the Michigan Road Test was to relate the compositional changes to pavement durability (wear and weathering qualities). The test was conducted on a six-mile test section where meticulous care was exercised in controlling mix and construction variables (e.g., aggregate gradation, binder content, temperatures, placing and compaction, and so forth). Although considered a well controlled experiment, the Michigan test did not result in any definition of a "desirable" asphalt as related to fractional composition.

3.4 Relationship Between Chemical Composition and Physical Properties

Four physical properties were measured for all samples:

Penetration at 4°C (ASTM-D5, AASHTO-T49)

Penetration at 25°C (ASTM-D5, AASHTO-T49)

Absolute Viscosity at 60°C (ASTM-D2171, AASHTO-T202)

Kinematic Viscosity at 135°C (ASTM-D2170, AASHTO-T201)

With the amount of data gathered during the research, it was possible to look for relationships among individual chemical fractions with each of the physical properties measured. The study of these relationships was done in two different groups:

a) Group 1, original samples combined with RTFO samples (Figures 3.10 through 3.13) and,

b) Group 2, recovered asphalt using Method-A (Figures 3.14 through 3.17).

The analysis made in Section 3.2 indicates that compositional profile of recovered asphalt is different to that of original and/or RTFO samples

(Figures 3.1 through 3.6); for this reason the study of relationships between physical properties versus chemical fractions should be treated separately.

The relationships for each physical property versus chemical composition for both groups of asphalt are shown in Figures 3.7 through 3.14. Each figure shows two graphs in two separate "windows" to depict more clearly the relation of each physical property against each of the four chemical fractions.

3.4.1 Penetration at 4°C versus Chemical Composition

Figure 3.10 shows the relationships for original and RTFO samples. Figure 3.14 shows the relationships for recovered asphalt. The approximate vertical distribution of the saturates, naphthene-aromatics, and polar-aromatics data points indicates that penetration at 4°C is independent from the percentage of these three fractions or very sensitive to changes in the percentage of any of these fractions. The variable distribution of the asphaltene fraction may indicate the following two effects:

- The asphaltene fraction does have an impact on the penetration at 4°C, but the data are scattered and, therefore, some other physico-chemical property of the asphaltenes may be significant.
- The test for penetration, in general, may not be sensitive enough and/or because of its empirical nature, the test does not measure the effect of other variables such as: shear rate, shear stresses, and changes in volume (13).

3.4.2 Penetration at 25°C versus Chemical Composition

Figure 3.11 shows the relationships for original and RTFO samples. Figure 3.15 shows the relationships for recovered asphalt.

The relationships between chemical fractions and penetration at 25°C were found to be similar to those found for penetration at 4°C. The same reasoning given in section 3.4.1 may be applied here, since the same principles applied for penetration at 25°C could be applied to penetration at 25°C.

Although the relationships for penetration (both at 4°C and 25°C) versus chemical fractions look similar for both groups of samples (original plus RTFO and recovered asphalt), it was observed that the naphthene-aromatics and polar-aromatics showed "opposite" behavior in both groups of samples, i.e., for original plus RTFO samples the naphthene-aromatics show a larger variability than the polar aromatics. For recovered asphalt the larger variability was found for the polar-aromatics rather than for the naphthene-aromatics.

The observed phenomena above indicate again that the recovered asphalt may not necessarily represent the material that was in place in the road. The same reasoning given in 3.2 may be applied here to partially explain these differences in behavior between recovered asphalt and original asphalt.

3.4.3 Absolute Viscosity at 60°C versus Chemical Composition

Figure 3.12 shows the relationships for original and RTFO samples. Figure 3.16 shows the relationships for recovered asphalt. The relationships for viscosity at 60°C look very similar to those observed for the penetration tests. Nevertheless, for viscosity at 60°C, there were more noticeable trends for the relationships in all four fractions.

The relationship of asphaltenes content was more pronounced than for the penetration tests. Viscosity at 60°C showed some type of dependency to the percent concentration of the asphaltene fraction, but with a large variability in the lower viscosity range. This variability may be attributed to the capillary viscometer since, recording lower viscosity values manually may be subject to more imprecision than in the higher range of viscosity.

The general trend for the relationship between viscosity at 60°C and asphaltenes indicates that the higher the asphaltene content the higher the viscosity. For the other three fractions the relationship is opposite.

Comparing results of original plus RTFO samples with recovered asphalt it can be observed that the relationships plotted are similar. The same phenomenon with naphthene and polar aromatics observed in the penetration test were observed with viscosity at 60°C, i.e., the naphthene-aromatic fractions show a larger variability for original samples rather than for recovered asphalt and vice versa for the polar-aromatics fraction.

3.4.4 Kinematic Viscosity versus Chemical Composition

Figure 3.13 shows the relationships for original plus RTFO samples. Figure 3.17 shows the relationships for recovered asphalt. Both figures show the kinematic viscosity axis in logarithmic scale.

The logarithmic viscosity at 135°C shows a very good relationship to all four fractions for both original asphalt and recovered asphalt. The greater the percent content of asphaltenes and the lower the percent content of the other three fractions, the higher the viscosity at 135°C.

The reason for having a better relationship between a physical flow property measured in the higher temperature range (viscosity at 135°C) and chemical fractions, may be explained by the following extract from a paper by Petersen (14):

> At higher temperatures (Newtonian flow region) the polar interactions between molecules dominate in influencing the flow behavior and the effect of molecular shape or geometry are minimized. At lower temperatures, the kinetic energy of the molecules is lowered and the molecules tend to associate or agglomerate into immobilized entities with a more or less ordered spatial arrangement which is influenced by the geometry of the molecule and its polar functionality.

Thus, at lower temperatures the flow property of asphalt may not only be influenced by the percent concentration of certain type of molecules but also by its polar functionality, spatial arrangement and geometry.

3.5 Relationship Between Chemical Composition and Temperature Susceptibility

The temperature susceptibility parameters considered in this study were those described in section 2.5. Temperature susceptibility can be defined as the rate of change of viscosity (or other measure of asphalt consistency) with temperature. Asphalt temperature susceptibility is highly dependent on the temperature range considered and directly related to the type of equipment used to determine asphalt consistency (12).

As in the evaluation of chemical composition versus physical properties (section 3.4), the study between chemical composition versus viscosity temperature susceptibility indices was done in two separate groups:

a) Group 1, original samples combined with RTFO samples (Figures 3.18 through 3.21) and,

b) Group 2, recovered asphalt using Method-A (Figures 3.22 through 3.25).

The reason for treating original samples separate from recovered asphalt was discussed in sections 3.2 and 3.4.

3.5.1 Penetration Index (PI) versus Chemical Composition

The penetration index values were calculated using penetration at 25°C (Pen 25) and viscosity at 60°C (Vis 60)(15). Figure 3.18 shows the relation for original and RTFO samples and Figure 3.22 shows the relation for recovered asphalt. It appears that by combining Pen 25 and Vis 60 into index the relationships to each of the four fractions were improved. Since Pen 25 did not show a good relationship to asphaltene content, the penetration index showed a clear dependency to the percent content of asphaltene. The other three fractions also showed a better correlation to penetration index.

3.5.2 Viscosity Temperature Susceptibility (VTS) versus Chemical Fractions

The VTS parameter was obtained using the viscosity values measured at 60°C and 135°C. Figure 3.19 shows the relation for original and RTFO samples and Figure 3.23 shows the relation for recovered asphalt.

For both original plus RTFO samples there is a correlation between VTS and asphaltene content, although the data is scattered. The percent content of the other three fractions showed little deviations to changes in the VTS values for both original and recovered asphalt.

Although there was some type of correlation between the viscosity values measured at 60°C and 135°C and each of the four generic fraction it appears that the viscosity temperature susceptibility of asphalt within the above range of temperature was not clearly dependent on the fractional composition of asphalt.

3.5.3 Penetration Ratio (PR) versus Chemical Fractions

The Penetration Ratio relationships are shown in Figure 3.20 for original asphalt and Figure 3.24 for recovered asphalt. The penetration ratio parameter used here measures temperature susceptibility of asphalt in the temperature range of 4°C and 25°C.

There was a very clear correlation between all four chemical fractions and penetration ratio for original plus RTFO samples but poor correlation was observed for recovered asphalt. This big difference among both groups of samples may be explained partially with the same arguments given in section 3.2. Nevertheless, in the author's opinion, this phenomenon may show that the differences observed between original and recovered asphalt may be due to the recovery procedure where some kind of preferential molecules arrangement are destroyed, thus reducing any chance of common behavior within the range of temperature where penetration values were measured.

3.5.4 Penetration Viscosity Number (PVN) versus Chemical Composition

The PVN parameter calculated here uses the penetration value measured at 25°C and the kinematic viscosity measured at 135°C. Figure 3.21 shows the relation for original plus RTFO samples and Figure 3.25 shows the relation for recovered asphalt. This viscosity temperature parameter covers a larger range of temperature when compared to the other three parameters analyzed. Within this temperature range asphalt materials exhibit a wide range of consistency; thus, a poor relation was expected between the PVN values and chemical fractions.

Although, as seen from Figures 3.21 and 3.25, there was a poor relation for the PVN values, the relation with the PI values determined using a narrower temperature range were similarly bad. The authors have no reasonable explanation for this phenomenon other than to remind the reader that both of these temperature susceptibility parameters (PI and PVN) are based on empirical relationships between the different physical properties measured. Thus, these parameters are not fundamental equations for describing material behavior.

3.5.5 Comparison with Other Research - Relationship Between Chemical Composition and Temperature Susceptibility

Values of asphaltene content and temperature susceptibility for 70 asphalts were tabulated by Anderson and Dukatz (16) and later plotted by Button et al. (12). The viscosity temperature susceptibility index used in the study were: Penetration Index, Viscosity Temperature Susceptibility, and Penetration Viscosity Number. Button et al., did not observe any relation between any temperature susceptibility parameter and asphaltene content. The reason for the differences in these two studies (Button et al. and Thenoux et al.) may be explained as follows:

- The asphaltene fraction reported by Button et al. was obtained using the Rostler analysis (ASTM-D2006) where the asphaltene has been precipitated in n-pentane. The asphaltene fraction measured in this study, using the Corbett-Swarbrick procedure (ASTM-D4124), was precipitated in n-heptane. The amount of asphaltene precipitated with each of these two procedures are different (17).
- Button et al. (12) have plotted all seventy asphalts in one figure where laboratory asphalt and field asphalt are combined as one set of data. As reported earlier in this report (section 3.2), field asphalt shows a very different chemical

profile than "original" or laboratory asphalt thus, this should be treated separately.

- This research study used a limited number of asphalts and the data range was artificially increased by using laboratory aged asphalt together with original materials. Nevertheless, this was not done with the field asphalt and the same kind of correlation was found.

3.6 Response of Individual Asphalts

Up to this point, the asphalt analyses from all eight projects have been grouped as one set of data. This permits, to a certain extent, generalization of some of the findings. However, each asphalt used may be studied independently to find out how the aging effect (as measured by increases in hardening) relates to asphalt composition.

For each asphalt sample there are four data points that may be considered. These are original sample, sample after RTFO, sample recovered from the top of the core, and sample recovered from the bottom of the core. Unfortunately, the number of points is too small to use some statistical tools. Thus, a descriptive analysis was made in order to complement the discussion presented in sections 3.4 and 3.5.

To examine the relationship of each chemical fraction to all the physical properties and temperature susceptibility parameters used in the present study and for all eight projects, 256 plots were created and analyzed. These plots are not included in the report because they may unbalance the relative importance of the topics which have been discussed.

From the analysis of all 256 plots, the following general observations may be made:

1) All asphalt experienced changes in physical properties and fractional composition with aging. However, asphalts from projects 2, 4, and 5 experienced relatively small changes in chemical composition while their physical properties showed significant changes. Asphalt from project 6 showed the opposite behavior, i.e., relatively small changes in physical properties but significant changes in fractional composition. For asphalts from projects 1, 3, 7, and 8, there were significant changes in physical properties and fractional composition.

2) For all eight projects, the proportion of asphaltene fraction increased with asphalt consistency as measured by penetration at 4°C and 25°C and viscosity at 60°C and 135°C. At the same time, the proportion of the other three fractions were reduced.

3) The temperature susceptibility parameters showed very distinct behavior in all eight asphalts and among all four parameters used.

   Asphalt samples 1, 3, and 5 showed no variation in VTS and PVN with asphalt composition while PR and PI showed significant variations. Asphalt samples 2, 4, 6, and 8 showed erratic behavior in all four temperature susceptibility parameters. Sample 7 showed some type of correlation between chemical fractions and all four temperature susceptibility parameters.

From the above analysis, the only observation that can be made is that different asphalts behave differently and age differently.

The different types of behavior shown by all of the samples when changing from original to aged material suggests that, to better characterize asphalt properties after aging, more than one aging condition should be studied. For example, asphalt samples should be aged at three or four different RTFO conditions and, after measuring physical and/or chemical properties, the rate of changes in measured properties should be compared among the different asphalts subjected to study. Measuring absolute changes of asphalt properties based on one aging condition may not reflect the overall aging behavior of this material.

3.7 Comparison of Recovered Asphalt Using Four Different Extraction Procedures

Four methods were used to extract and recover asphalt samples from cores for projects 3, 5, and 7. The laboratory procedures for these four methods (A, B, C, and D) are summarized in Figure 2.3.

The physical properties and chemical composition analysis of the above samples are given in Tables 2.5 and 2.8, respectively. The results showed that all four methods of extraction and recovery did not give consistent results. Figure 3.26 shows the composition for each extraction method and clearly shows the differences encountered among the techniques used.

There may be a number of factors that contributed to the differences between extraction/recovery methods. Some of these reasons are:

- The extraction procedure of methods A and C uses high temperatures 104°C for a relatively long period of time (up to 2 hours), while for methods B and D the extraction procedure is done at room temperature. Another difference between the two major extraction procedures was in the filtering devices used;

the samples were centrifuged in all four methods to decant fine particles that were not filtered properly.

- The recovery procedure for methods A and B uses a completely different technique than that employed in methods C and D, the major difference being the gas environment employed to concentrate the asphalt from the solvent used. Methods A and B use carbon dioxide at a rate of 2000 mL/min while methods C and D use nitrogen at an unspecified rate. These differences are considered to be important as, from laboratory experience at Oregon State Highway Division (OSHD), it has been observed that variation of the flow rate of the inert gas used in the concentration causes differences in asphalt extracted from the same cores.
- A third difference to be considered in the present analysis is related to the familiarity of the laboratory technicians with the procedures used. Method A is the only procedure that has been used in routine work for a number of years while the other three methods were used in this research study for the first time.

3.8 Analysis of the Fraass Test Results and POB Aging Test

This part of the study constitutes an extension of the overall objectives of the research. The POB test was used together with the RTFO test to produce accelerated aging in asphalt binders.

The POB device was used in conjunction with the Fraass test to evaluate oxidative aging. Samples were prepared on Fraass plates and tested for "Fraass Breaking Point" (Institute of Petroleum IP-80/53) before and after aging. Changes in Fraass temperature and in fractional composition were analyzed.

Figure 3.27 shows the relationships between the Fraass temperature and all four fractional components for results from three projects studied (Projects 3, 5, and 7) before and after aging. Figure 3.27 shows that the asphaltene content is the only fraction that has a relationship with the Fraass temperature while the other three fractions are more independent.

Figure 3.28 shows a similar relationship to the one above but is arranged so that each project can be analyzed separately and the effects of each of the aging procedures used can be compared. Based on the three samples used (a small sample size), the following effects can be observed:

a) The POB 5-day test was the most severe aging test, i.e., it caused much greater changes in composition than the RTFO.

b) The asphaltene content increases with aging but the initial asphaltene content of any of the original samples was not related to the total amount of aging after RTFO and POB tests.

c) Project 5 was the most susceptible to aging based on laboratory "performance."

The relationship of these results with field performance is discussed in Chapter 4.

Table 3.1: Relationship Equations for Chemical Fractions.

	Relationship	Original + RTFO			Recover by Method-A	
		Linear Relation	R	Range (+ or -)	Linear Relation	R
1	Saturates vs Asphaltenes	%SA = 12.69-0.197%Asp	0.87	0.93	%SA = 14.49-0.231%Asp	0.89
2	N-Aromatics vs Asphaltenes	%NA = 35.24-0.489%Asp	0.95	2.64	%NA = 27.46-0.206%Asp	0.81
3	P-Aromatics vs Asphaltenes	%PA = 50.65-0.297%Asp	0.87	1.59	%PA = 55.46-0.506%Asp	0.97
4	Saturates vs N-Aromatics	%SA = - 0.78+0.376%NA	0.81	-	%SA = - 9.42+0.808%NA	0.58
5	Saturates vs P-Aromatics	%SA = - 16.63+0.569%PA	0.75	-	%SA = -10.39+0.446%PA	0.87
6	N-Aromatics vs P-Aromatics	%NA = - 34.35+1.341%PA	0.72	-	%NA = - 6.05+0.379%PA	0.72

Table 3.2: Relation with other Studies. The Michigan Road Test (11).

Fractions	Wyoming-A		Boscan Venezuela		Wyoming-B		Texas Winkler		Arkansas Smackover		Texas Talco		Sample
	Test (a)	Eq. (b)	Test	Eq.	Test	Eq.	Test	Eq.	Test	Eq.	Test	Eq.	
Asphaltenes	16.0	(=x)	19.2	(=x)	12.0	(=x)	12.8	(=x)	13.3	(=x)	19.7	(=x)	Original
Saturates	9.8	9.5	6.0	8.9	8.6	10.3	13.9	10.2	7.9	10.1	8.6	8.8	"
N-Aromatics	32.5	27.4	28.8	25.9	32.6	29.4	31.3	29.0	42.0	28.7	38.7	25.6	"
P-Aromatics	41.7	42.8	45.1	41.3	46.7	44.8	40.9	44.4	36.5	44.1	32.4	41.0	"
Asphaltenes	19.3	(=x)	27.7	(=x)	19.4	(=x)	20.3	(=x)	20.7	(=x)	28.8	(=x)	Top
Saturates	9.8	9.8	7.1	8.1	9.7	10.0	15.7	9.4	9.6	9.7	9.9	7.8	"
N-Aromatics	25.9	23.5	20.7	21.8	25.9	23.5	22.7	22.8	28.4	25.2	24.2	21.5	"
P-Aromatics	43.9	45.7	43.8	41.4	41.2	45.6	40.5	45.2	40.5	43.0	35.2	40.9	"
Asphaltenes	16.9	(=X)	22.8	(=X)	15.6	(=x)	15.0	(=x)	15.9	(=x)	24.7	(=x)	Base
Saturates	9.8	10.6	7.1	9.2	9.7	7.2	15.7	6.9	9.6	10.8	9.9	8.8	"
N-Aromatics	25.9	24.0	20.7	22.8	25.9	24.2	22.7	23.4	28.4	24.2	24.2	22.4	"
P-Aromatics	43.9	46.9	43.8	43.9	41.2	47.9	40.5	47.9	40.5	47.4	35.2	43.0	"
													"

(a) Test values from reference (11).
(b) Values from equations given in Table-14.

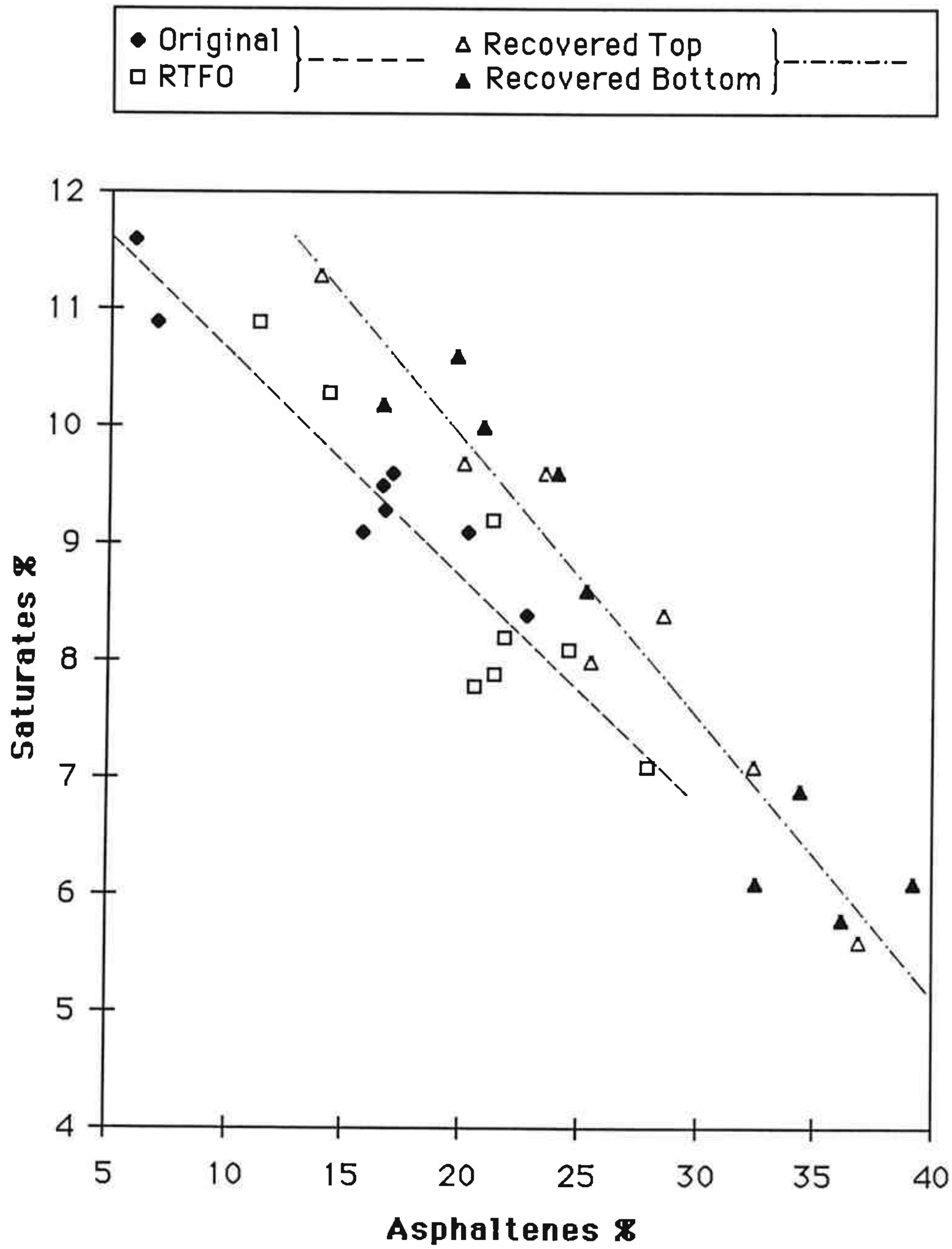

Figure 3.1: Saturates vs Asphaltenes

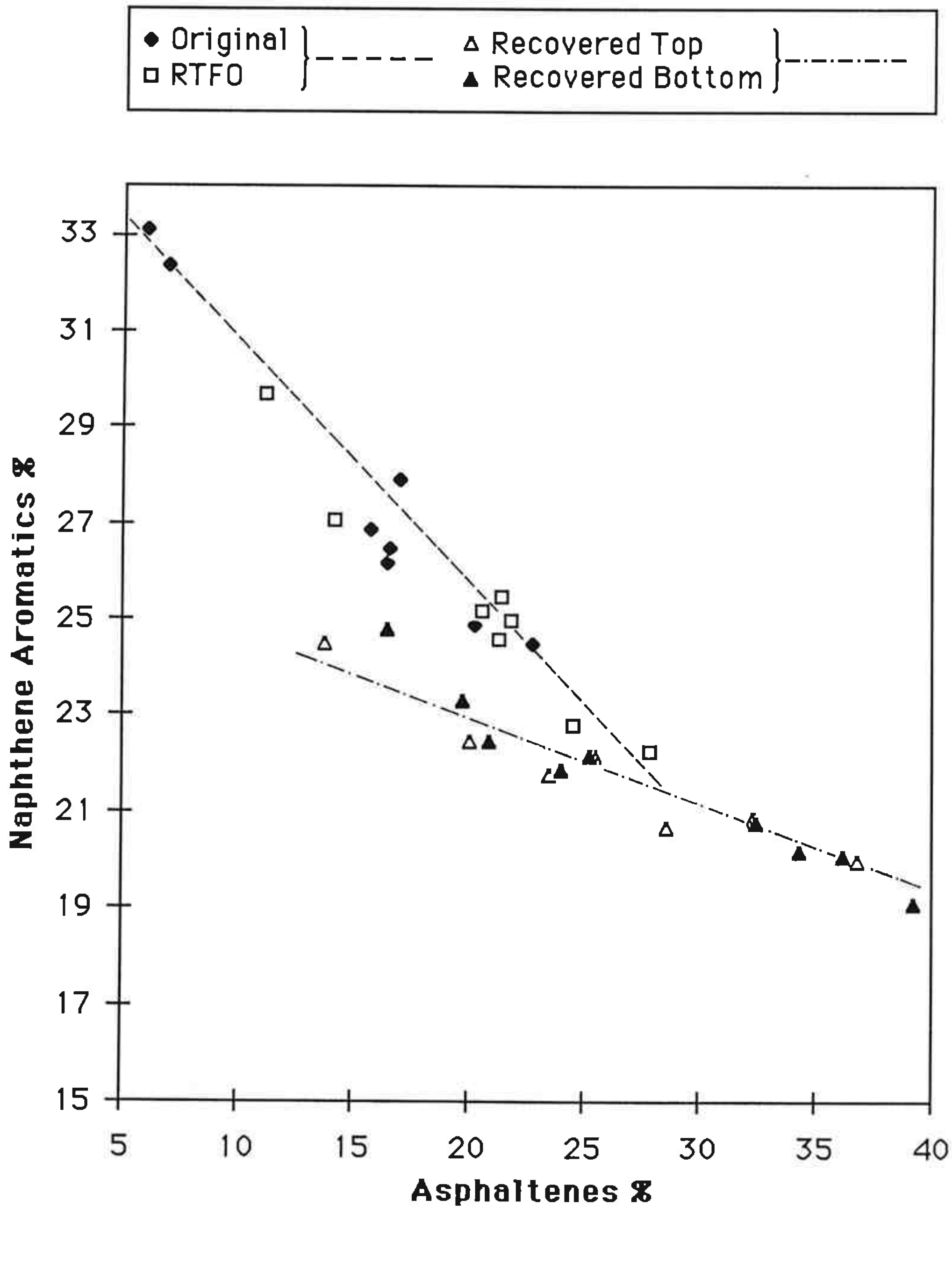

Figure 3.2 : Naphthene-Aromatics vs Asphaltenes

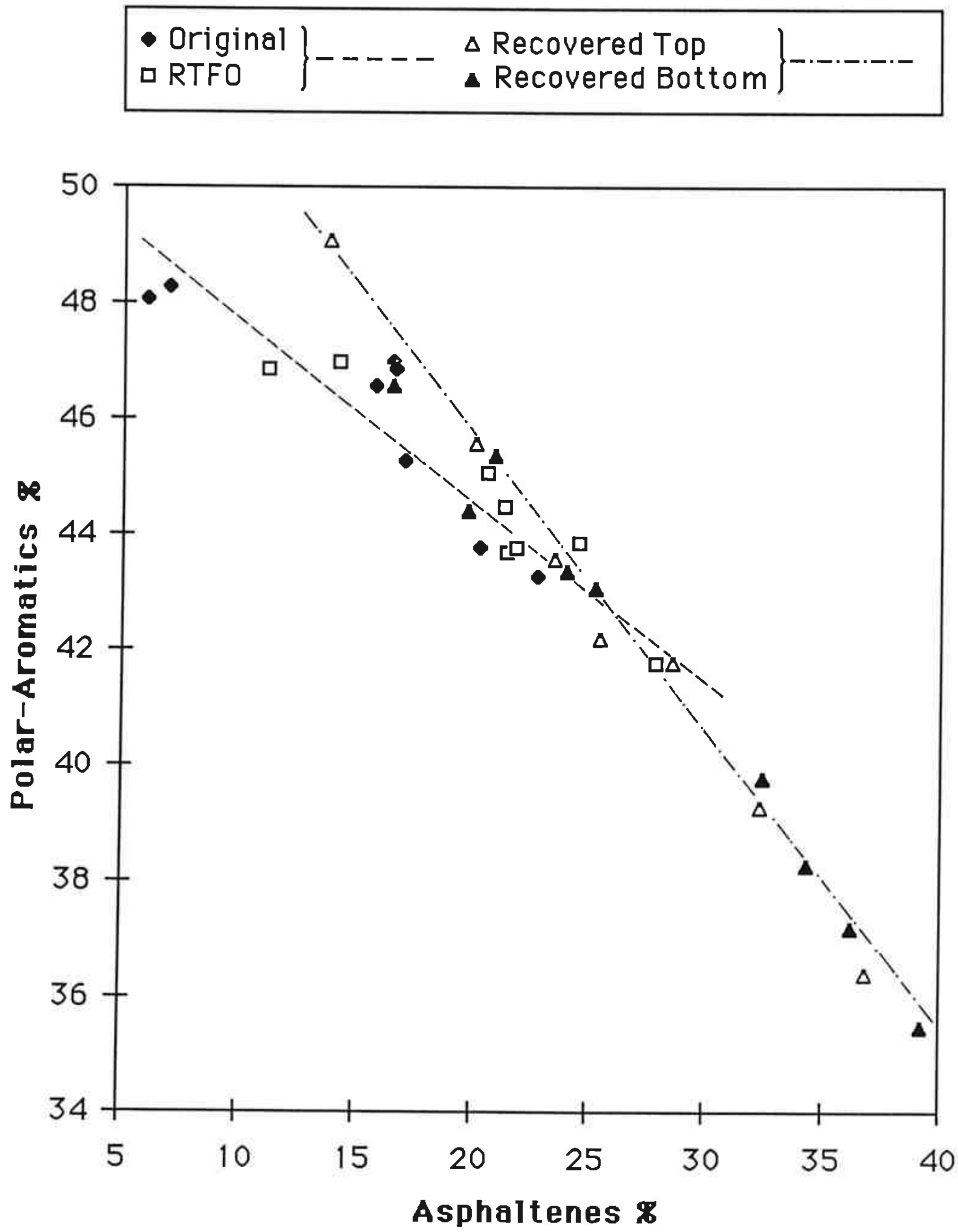

Figure 3.3: Polar-Aromatics vs Asphaltenes

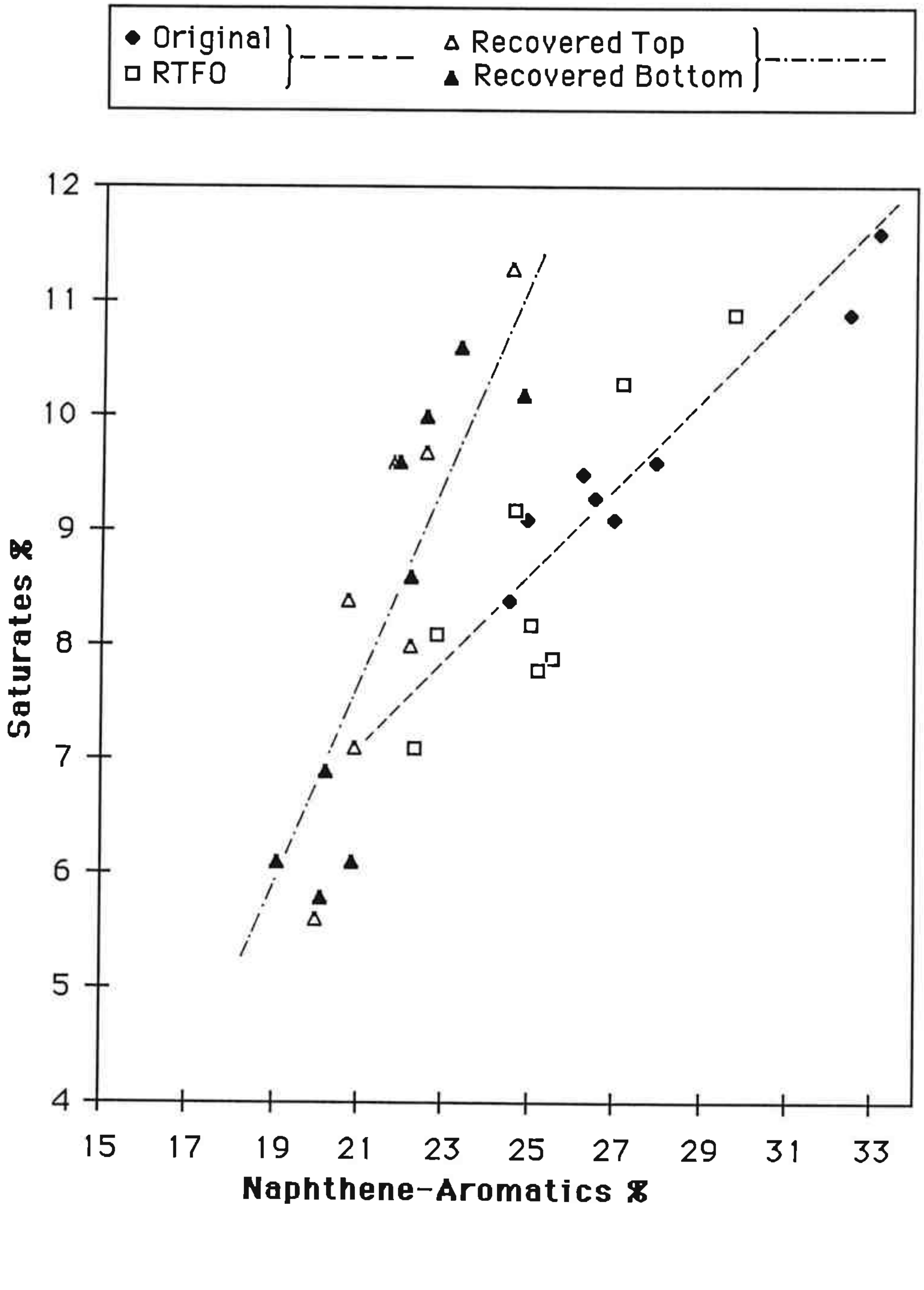

Figure 3.4: Saturates vs Naphthene-Aromatics

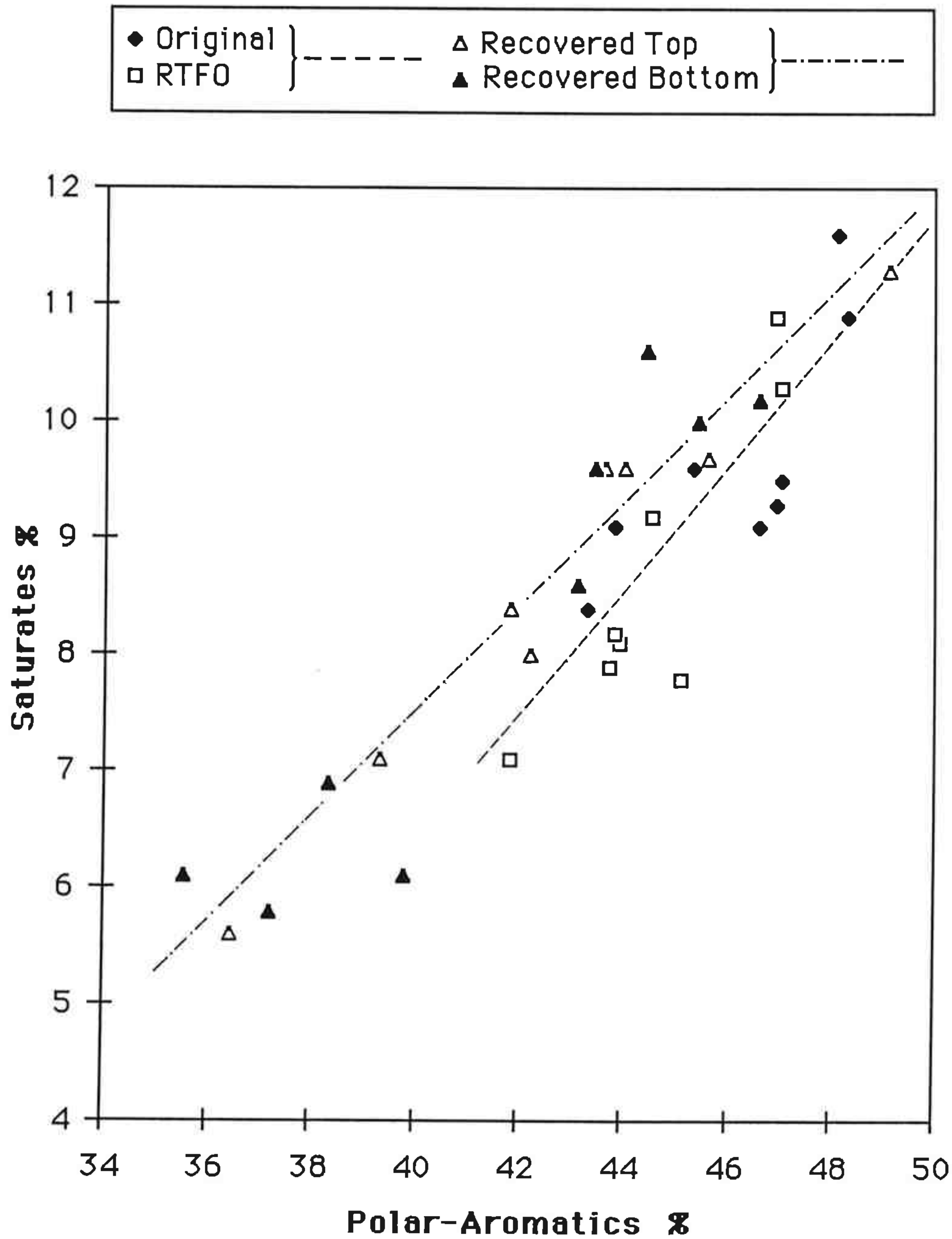

Figure 3.5: Saturates vs Polar-Aromatics

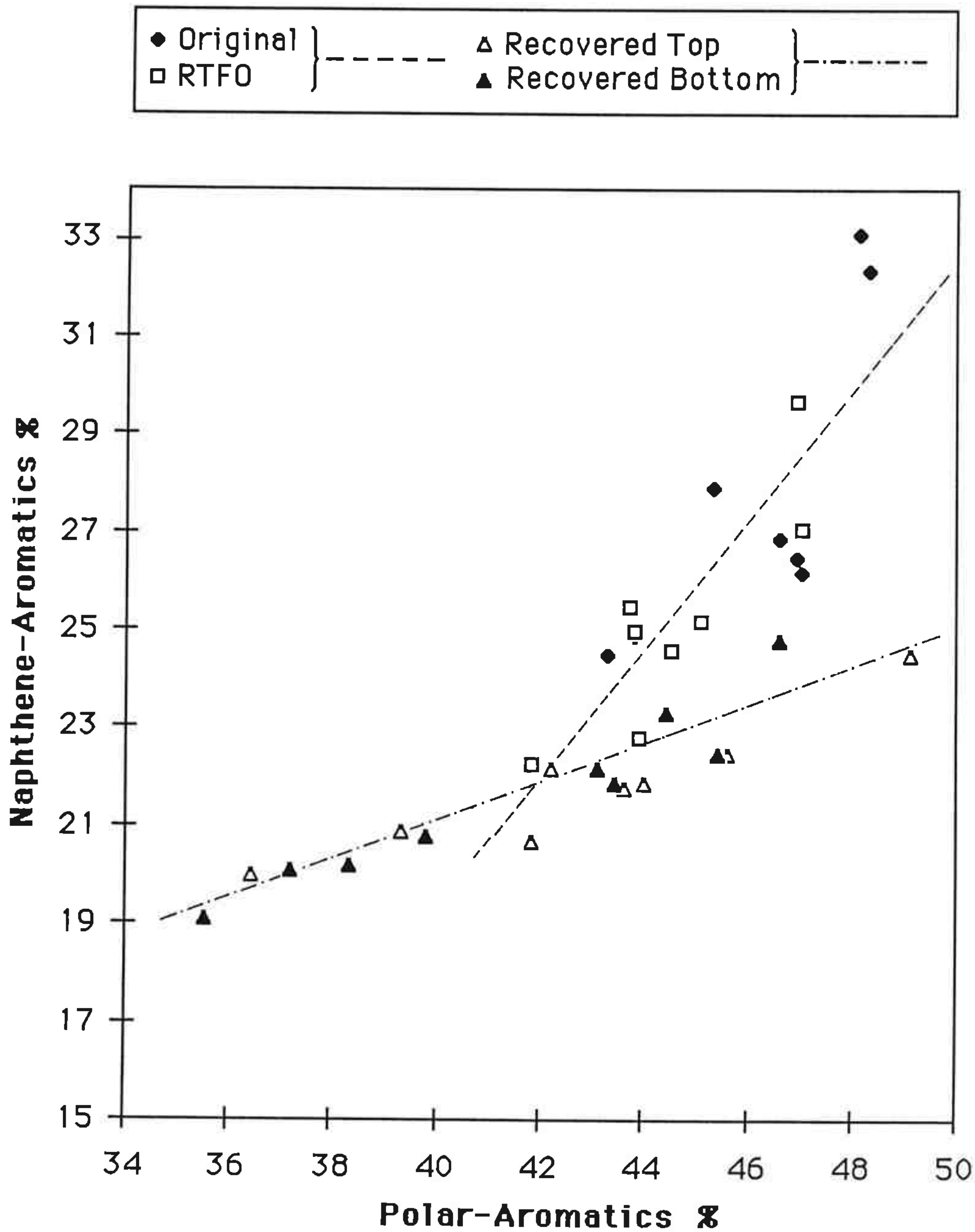

Figure 3.6: Naphthene-Aromatics vs Polar-Aromatics

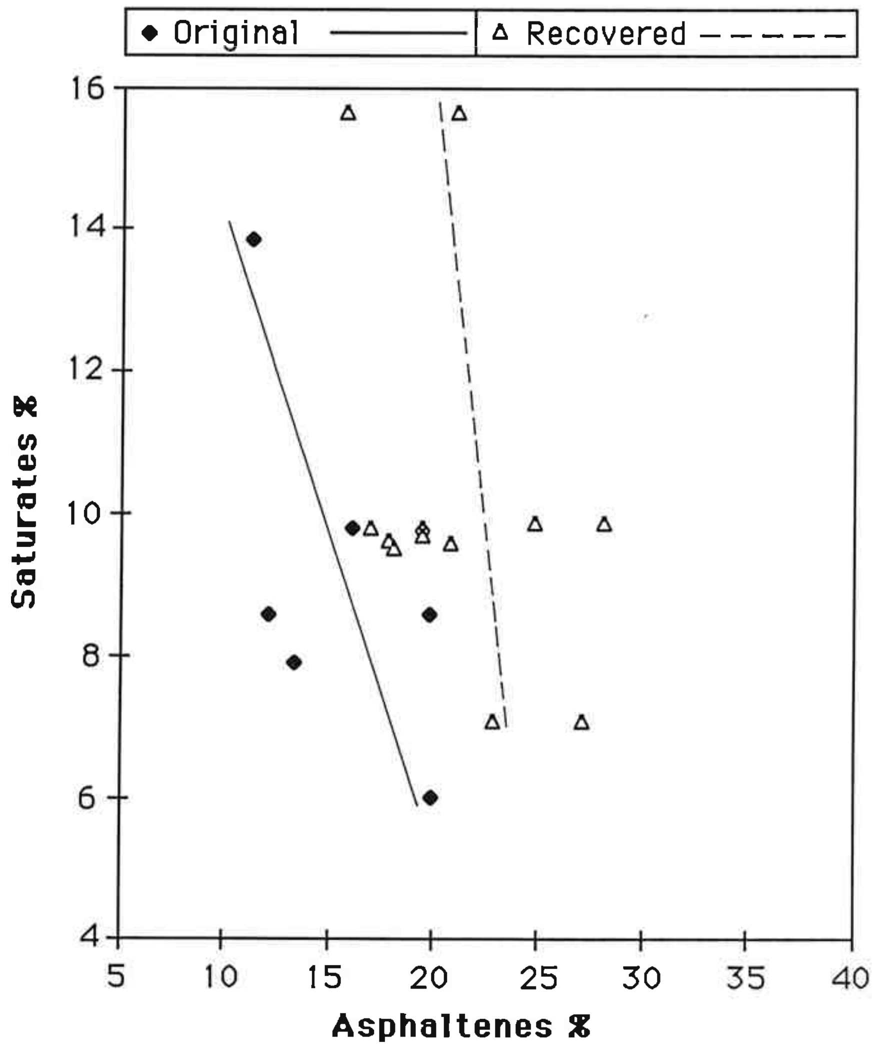

Figure 3.7: Saturates vs Asphaltenes.
The Michigan Road Test.

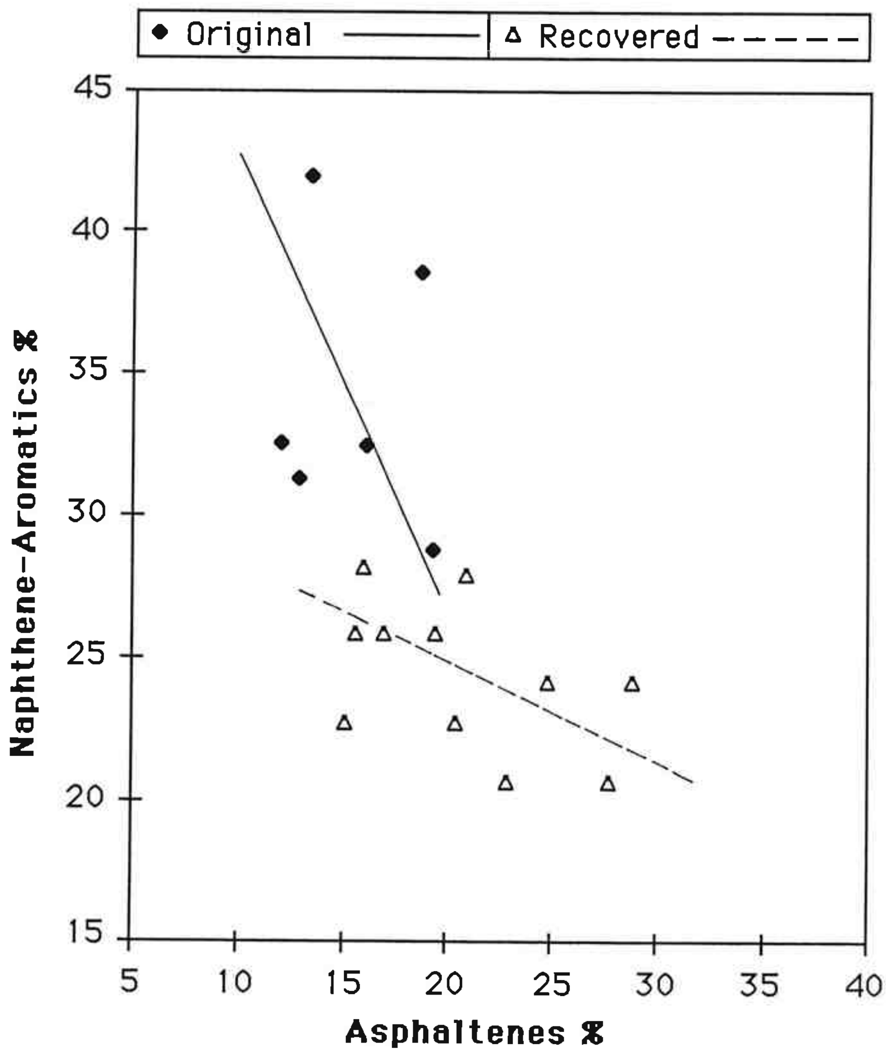

Figure 3.8: Naphthene-Aromatics vs Asphaltenes.
The Michigan Road Test.

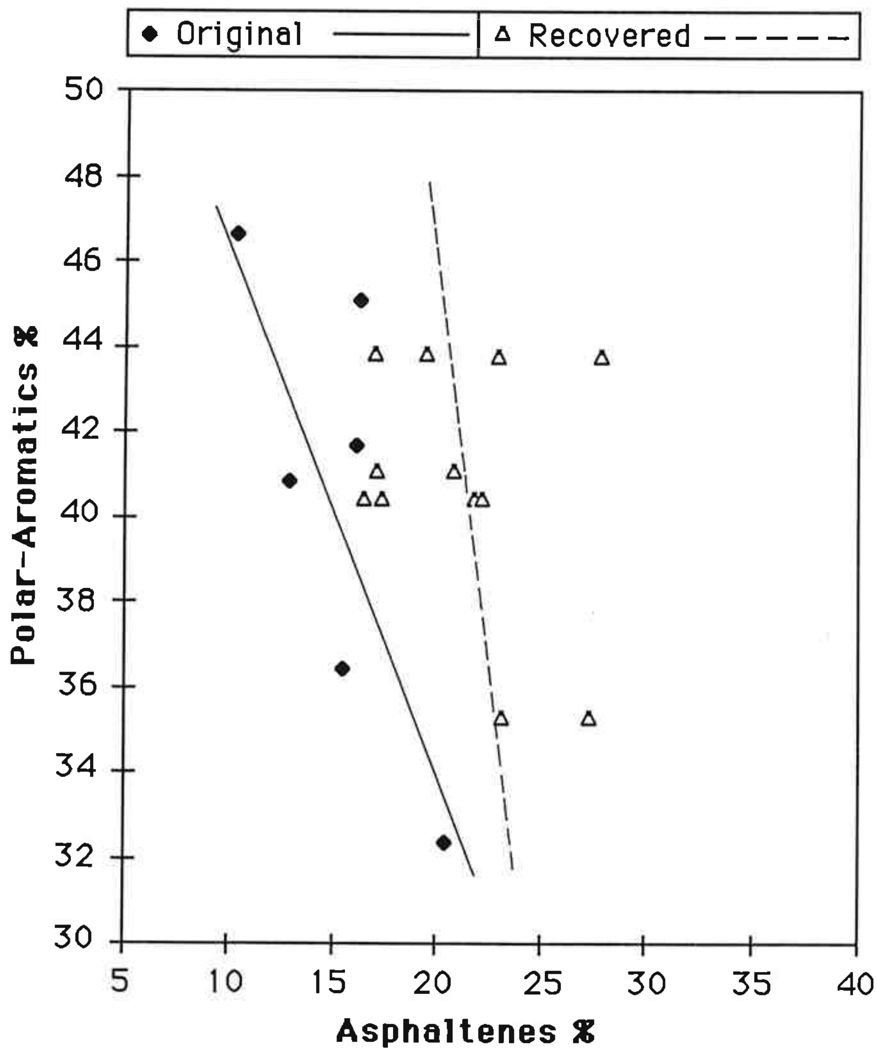

Figure 3.9: Polar-Aromatics vs Asphaltenes.
The Michigan Road Test.

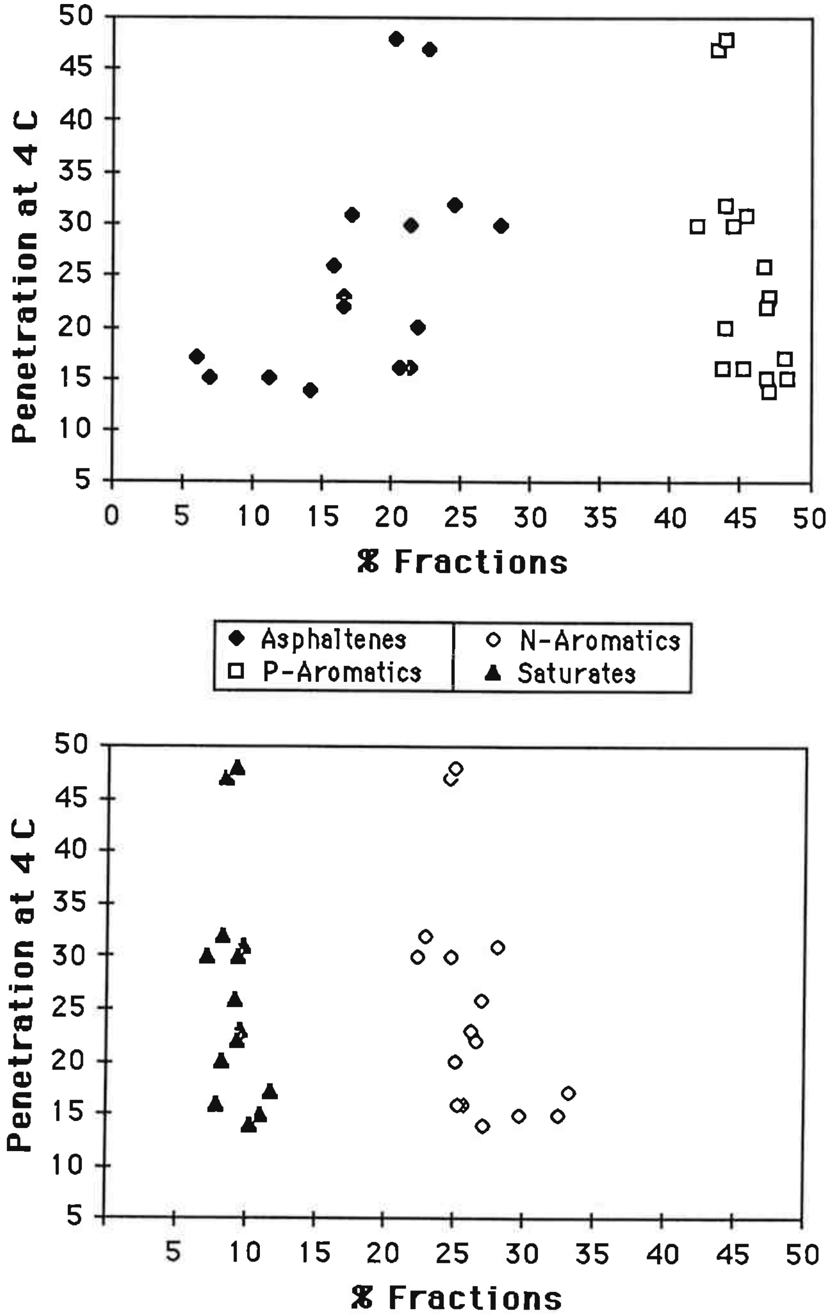

Figure 3.10: Penetration at 4 ^{0}C vs Chemical Fractions
Original and RTFO Samples

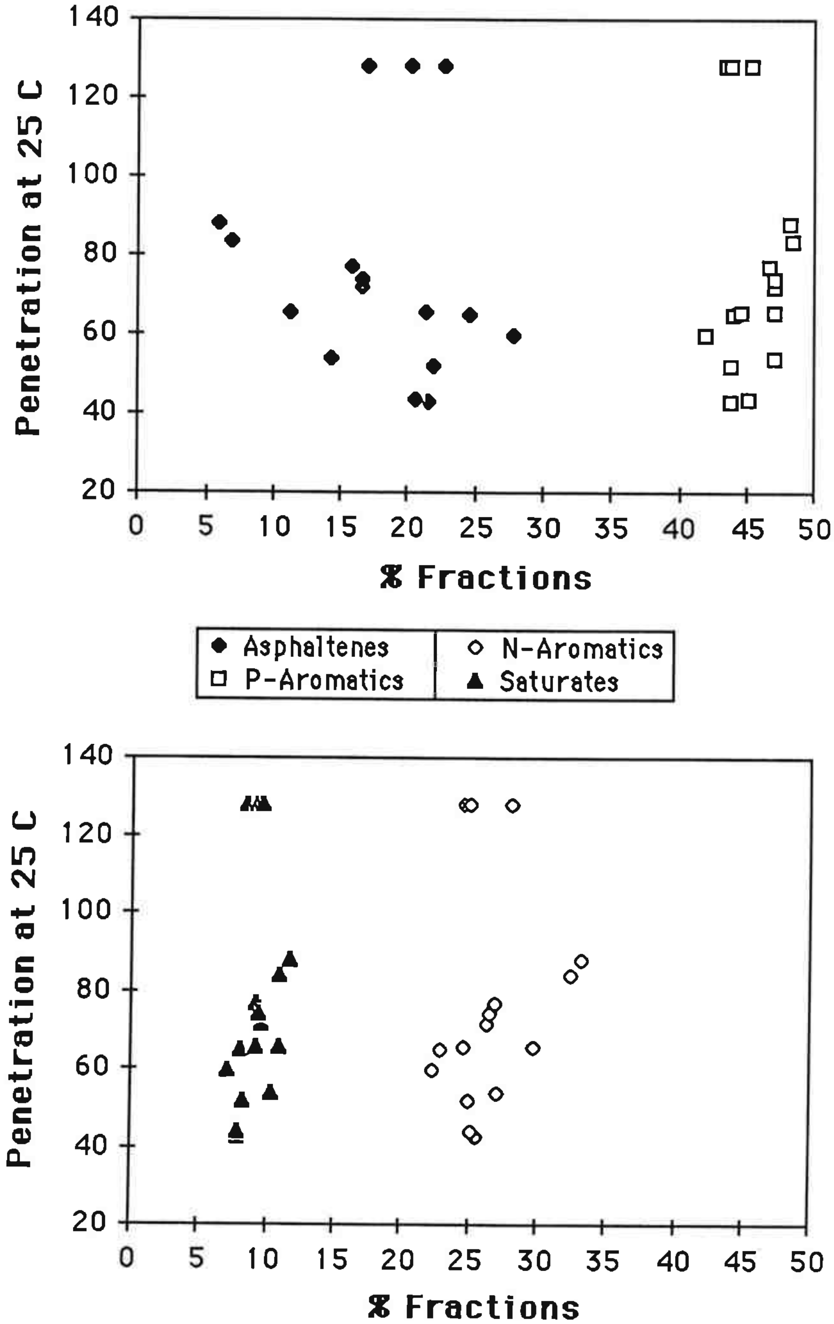

Figure 3.11: Penetration at 25 ^{o}C vs Chemical Fractions Original and RTFO Samples

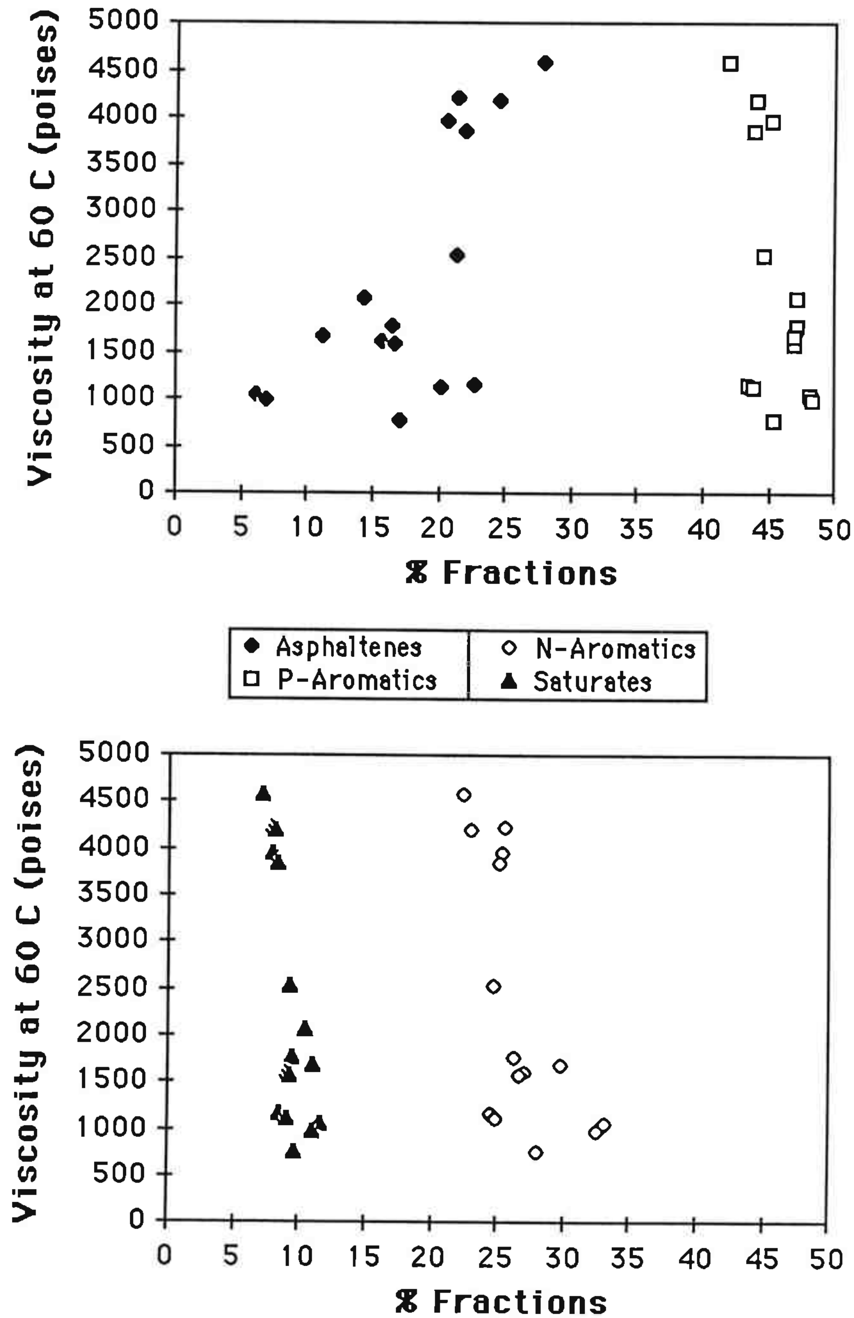

Figure 3.12 : Viscosity at 60 ^{0}C vs Chemical Fractions
Original and RTFO Samples

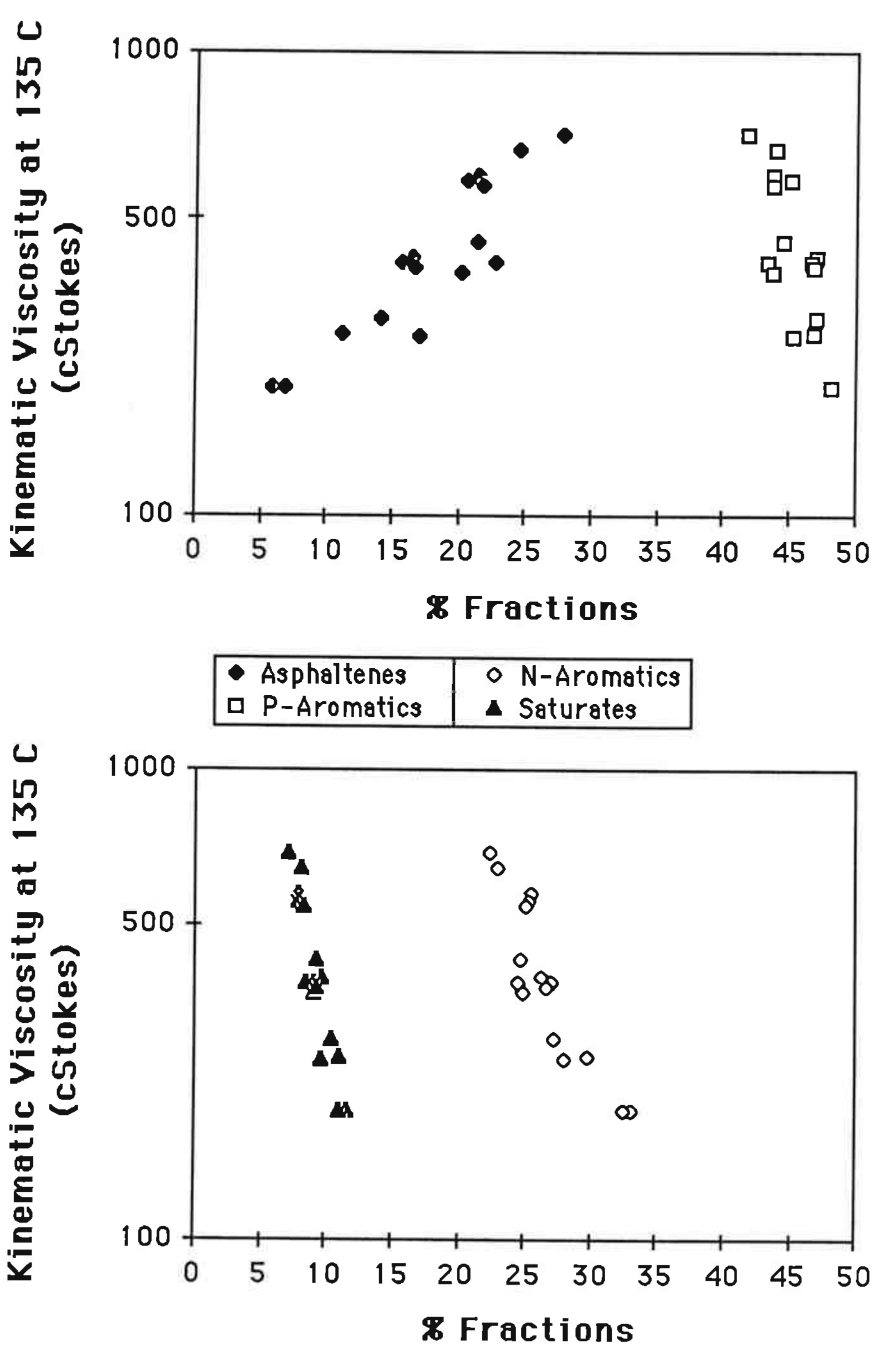

Figure 3.13: Kinematic Viscosity vs Chemical Fractions
Original and RTFO Samples

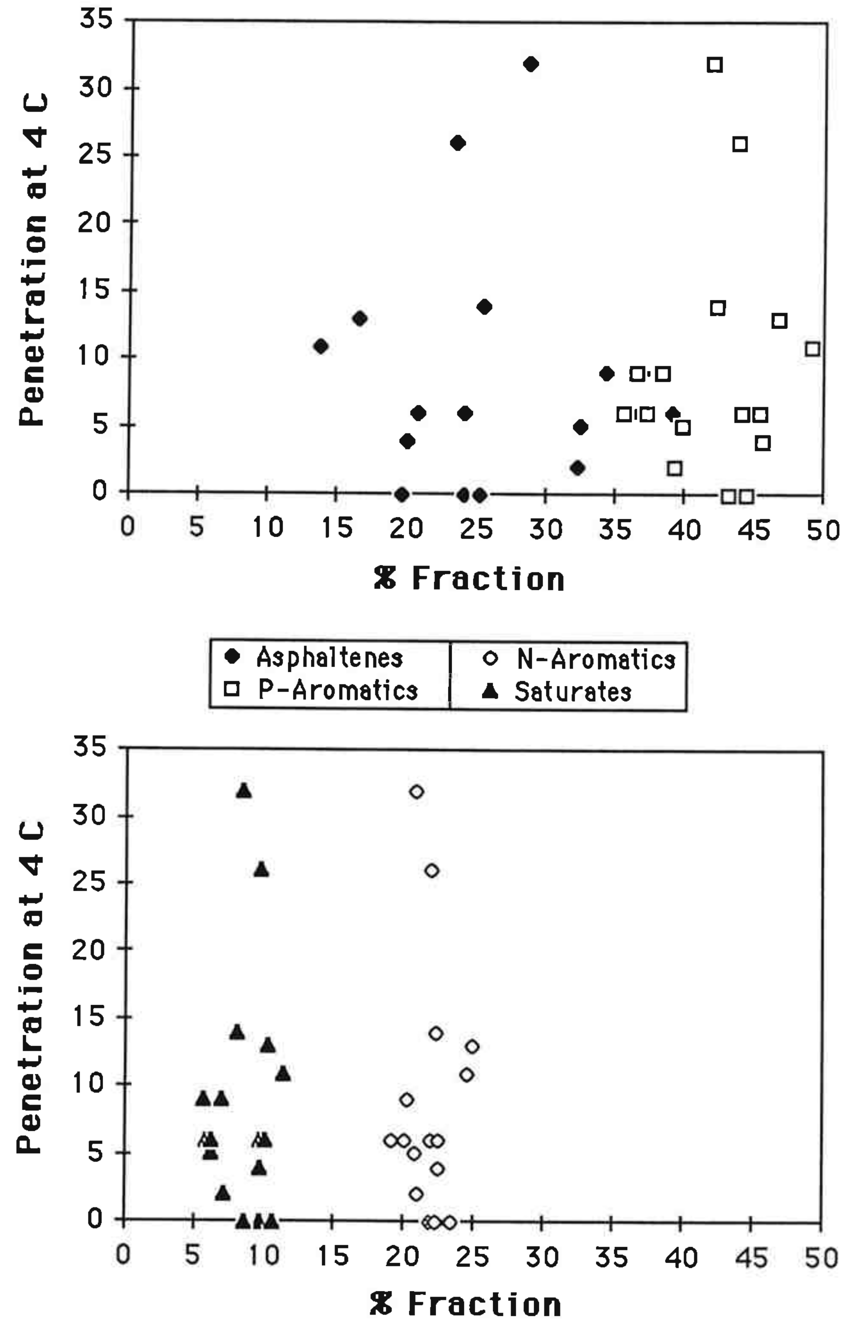

Figure 3.14: Penetration at 4 ^{o}C vs Chemical Fractions.
Recovery Method-A.

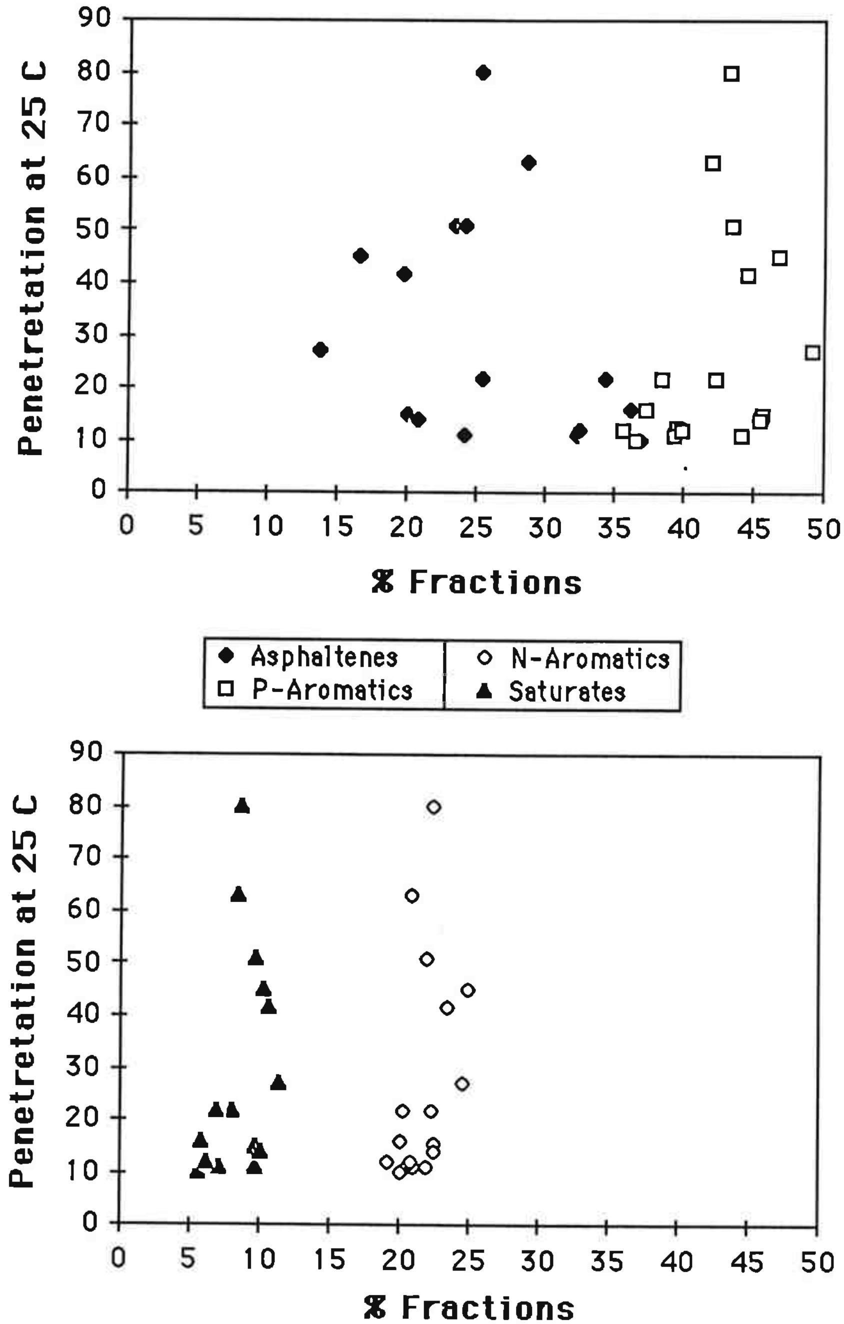

Figure 3.15 : Penetration at 25 ^{0}C vs Chemical Fractions. Recovery Method-A.

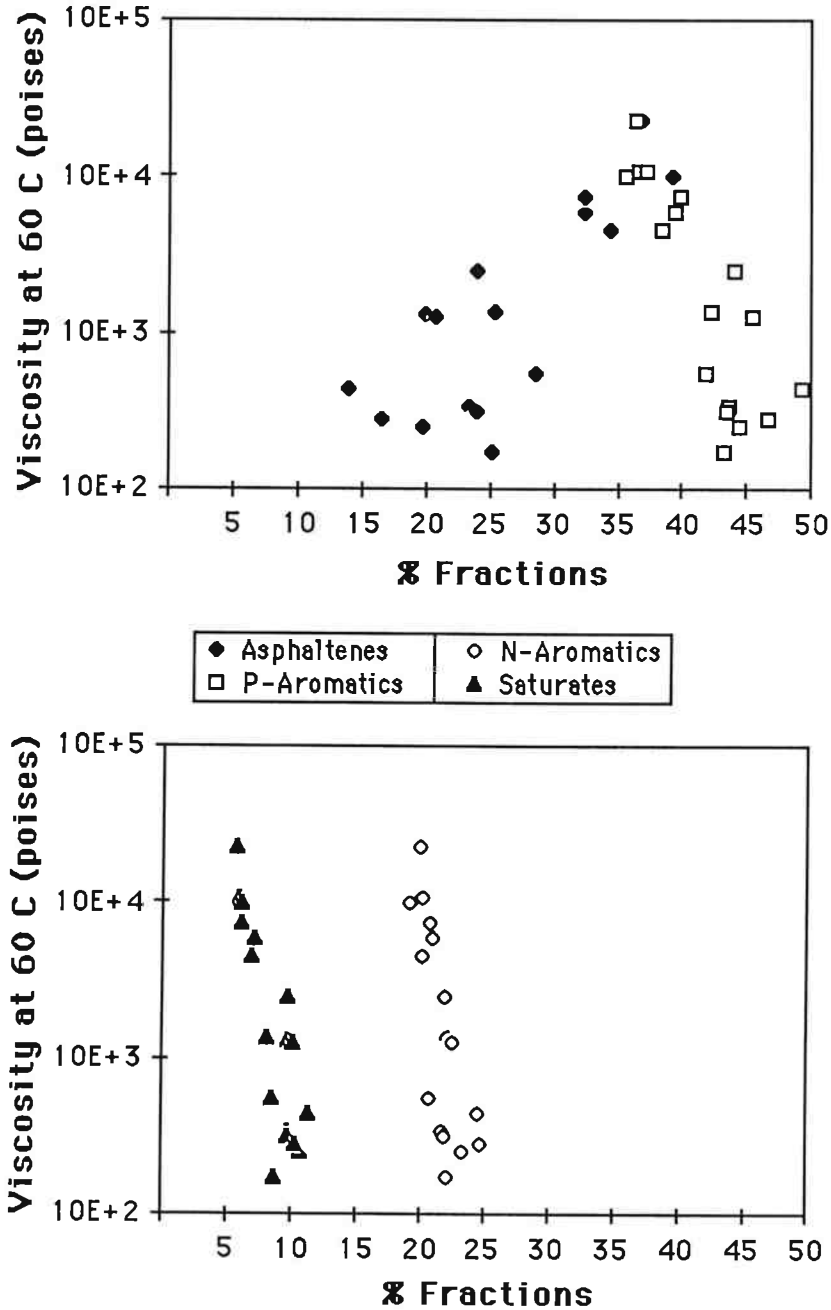

Figure 3.16 : Viscosity at 60 ^{0}C vs Chemical Fractions. Recovery Method-A.

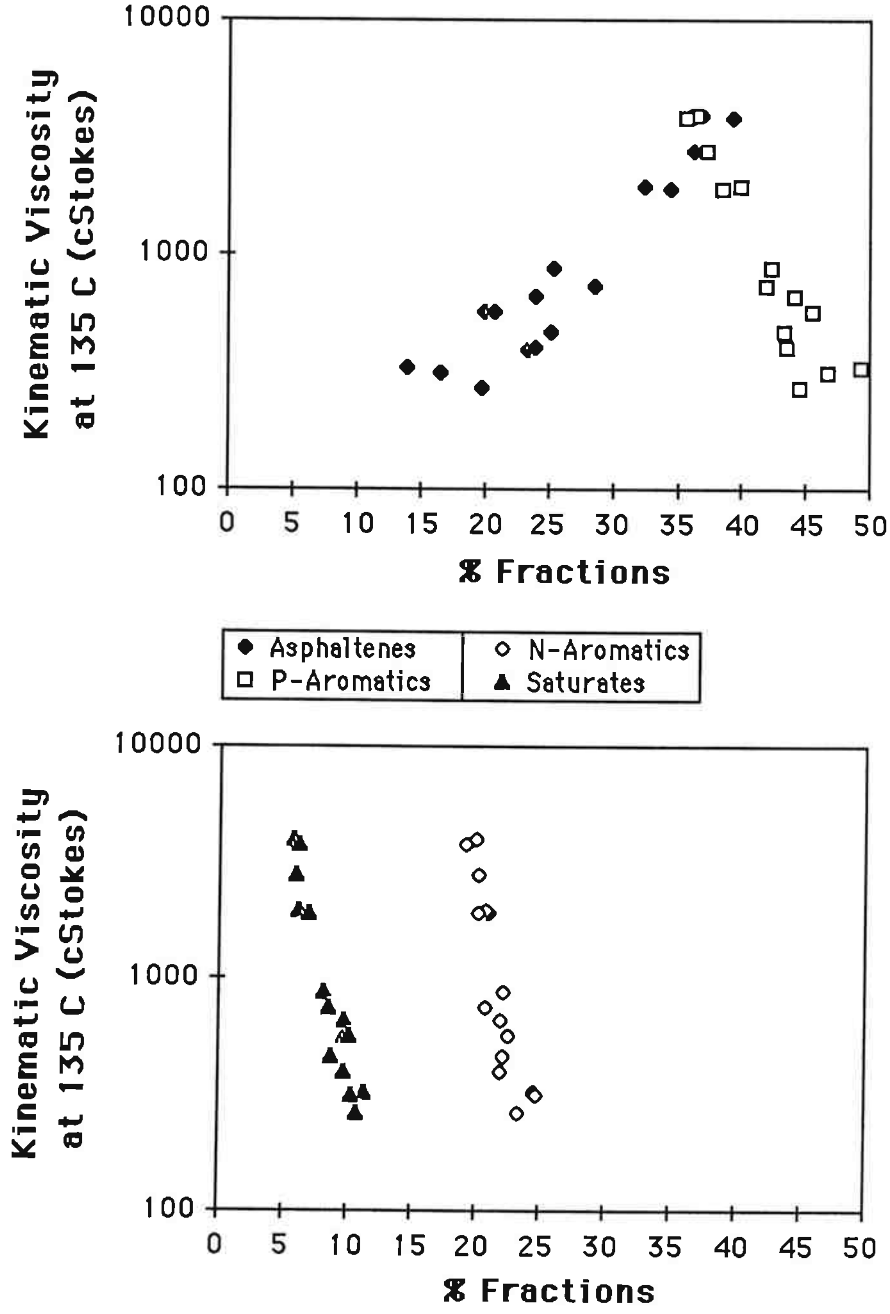

Figure 3.17: Kinematic Viscosity vs Chemical Fractions. Recovery Method-A.

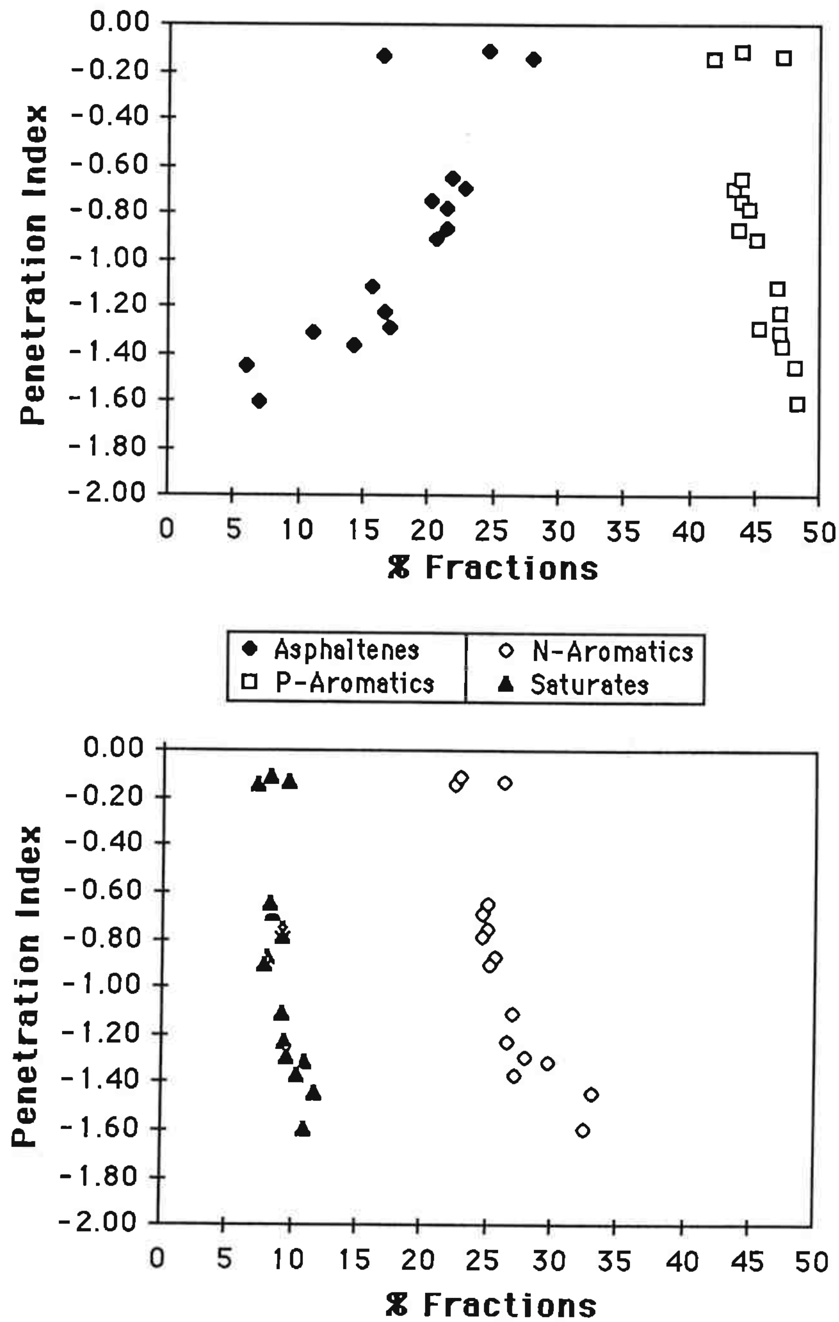

Figure 3.18 : Penetratio Index vs Chemical Fractions Original and RTFO Samples

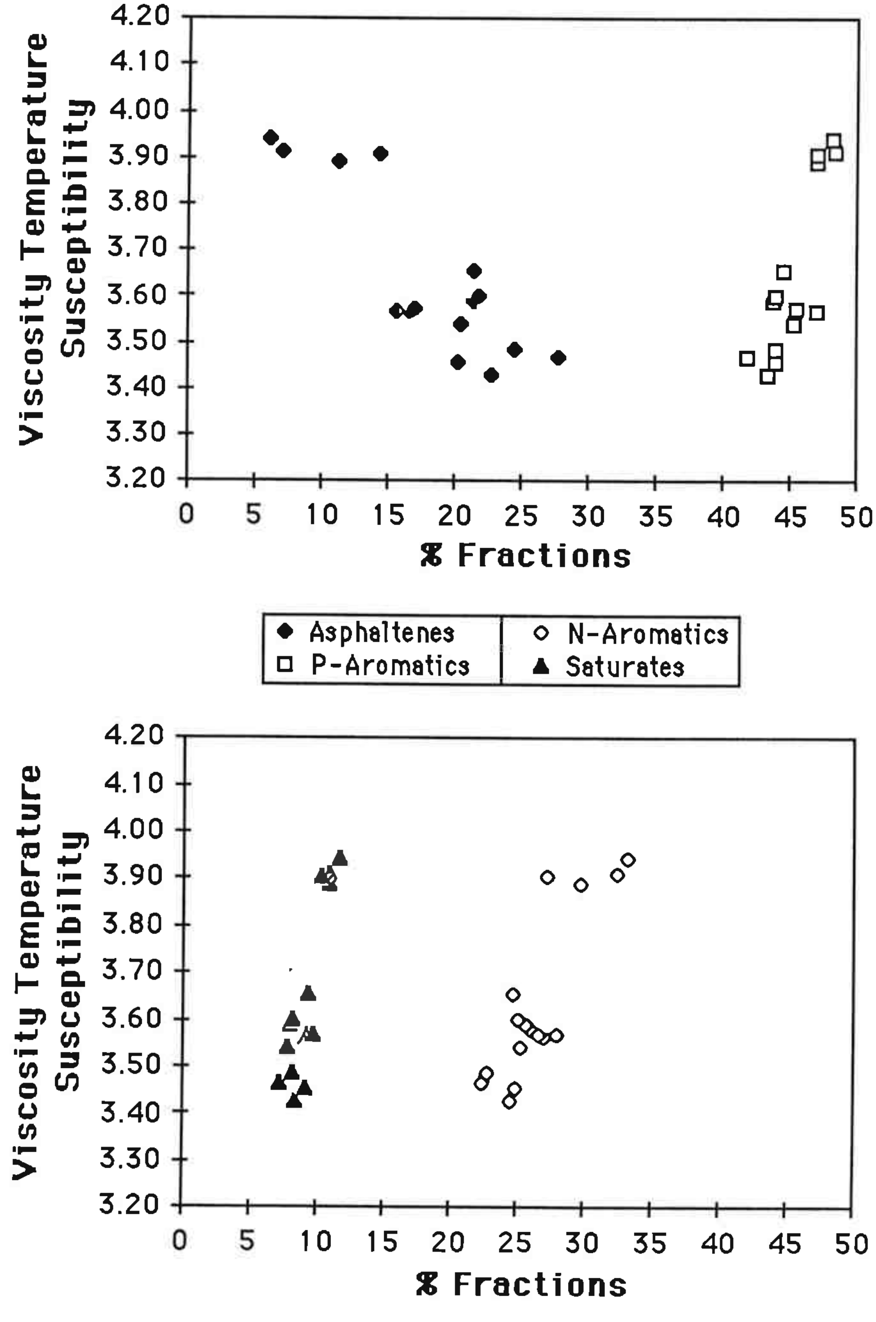

Figure 3.19 : Viscosity Temperature Susceptibility vs Chemical Fractions. Original and RTFO Samples

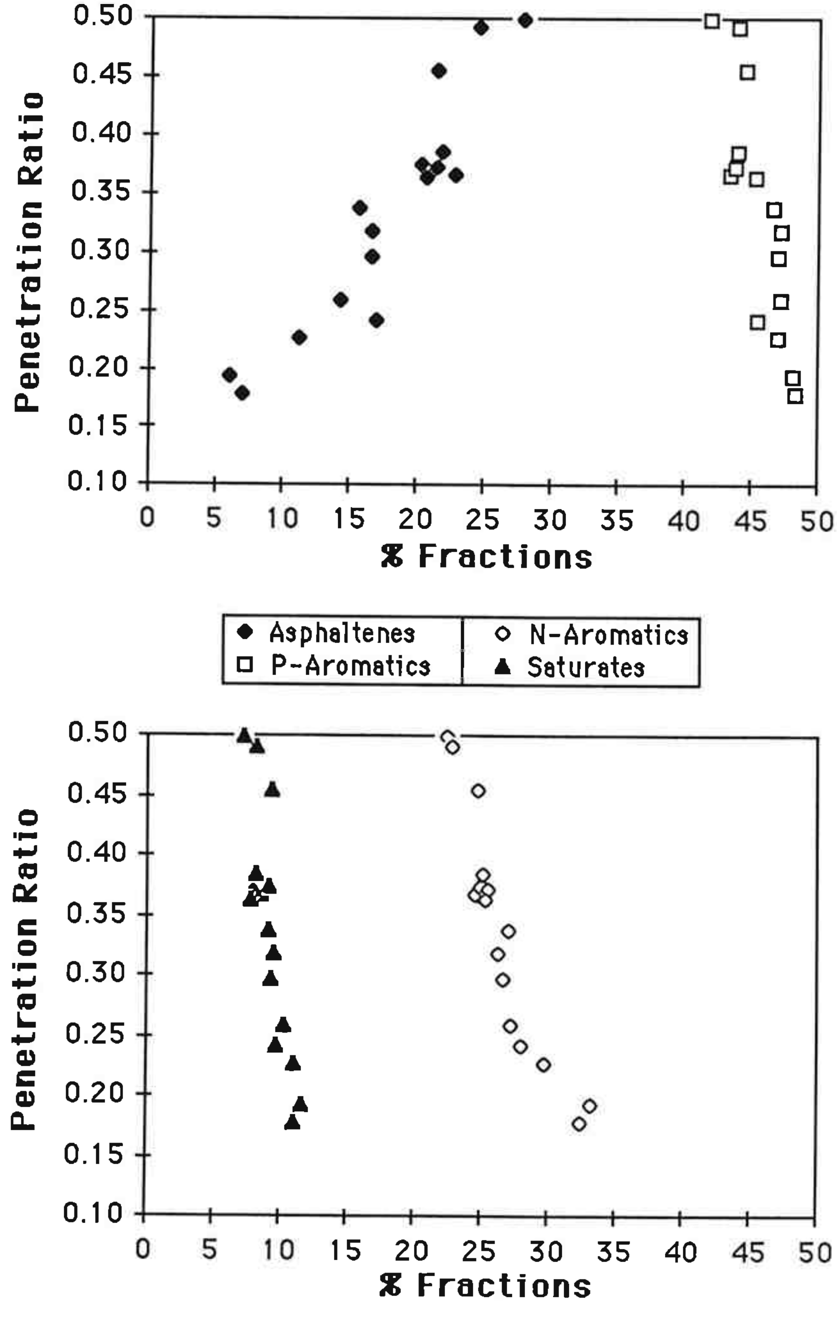

Figure 3.20: Penetration Ratio vs Chemical Fractions
Original and RTFO Samples

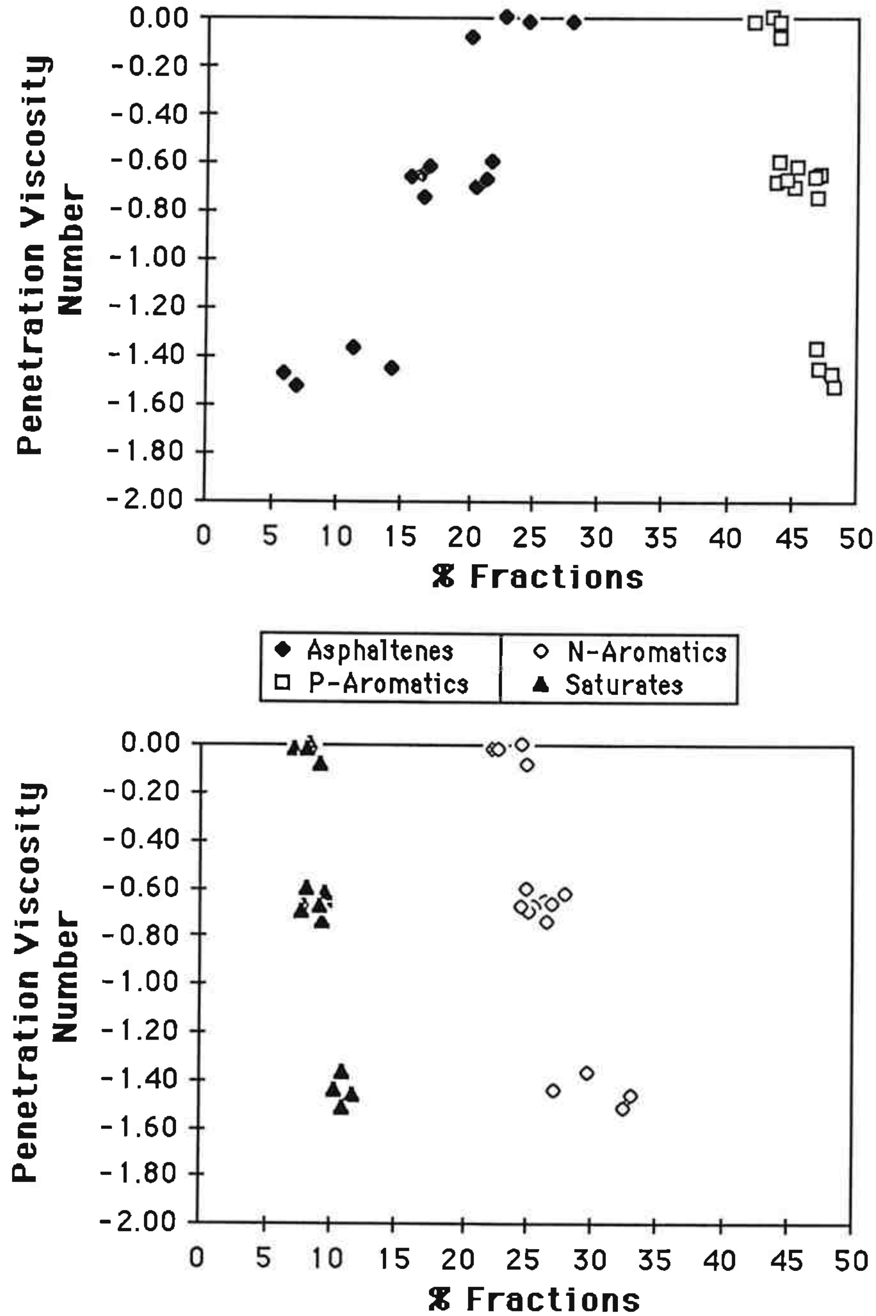

Figure 3.21: Penetration Viscosity Number vs Chemical Fractions. Original and RTFO Samples

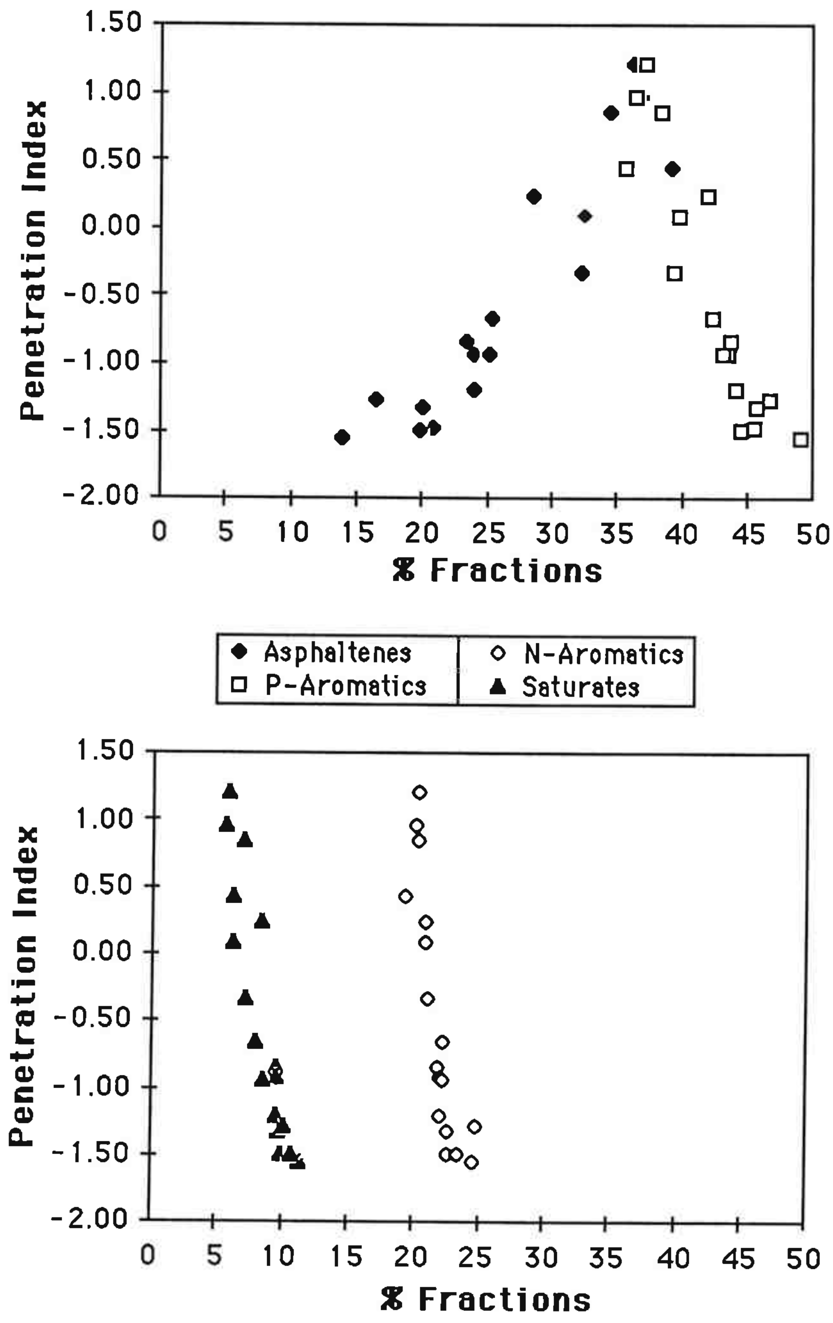

Figure 3.22: Penetration Index vs Chemical Fractions
Recovery Method-A

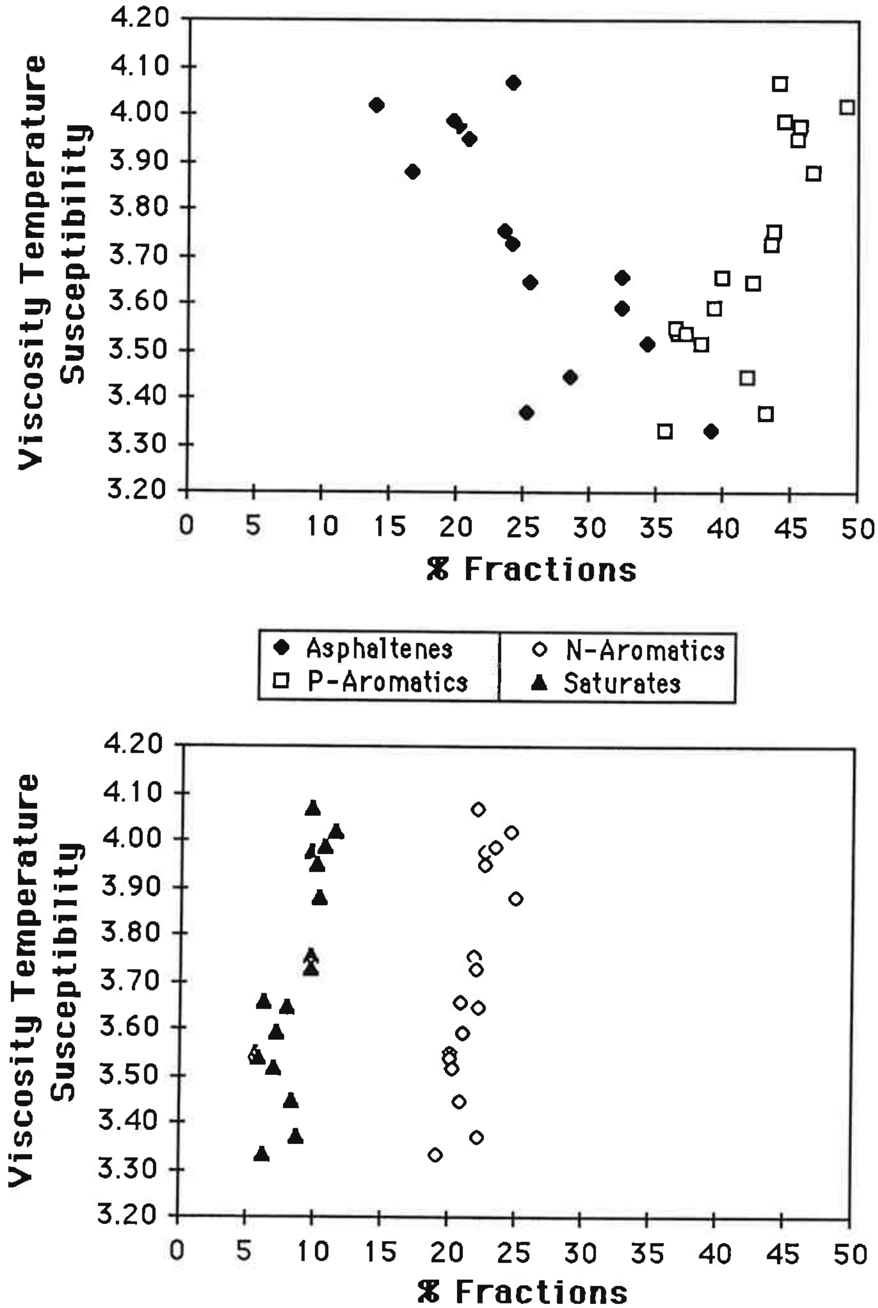

Figure 3.23: Viscosity Temperature Susceptibility vs Chemical Fractions. Recovery Method-A

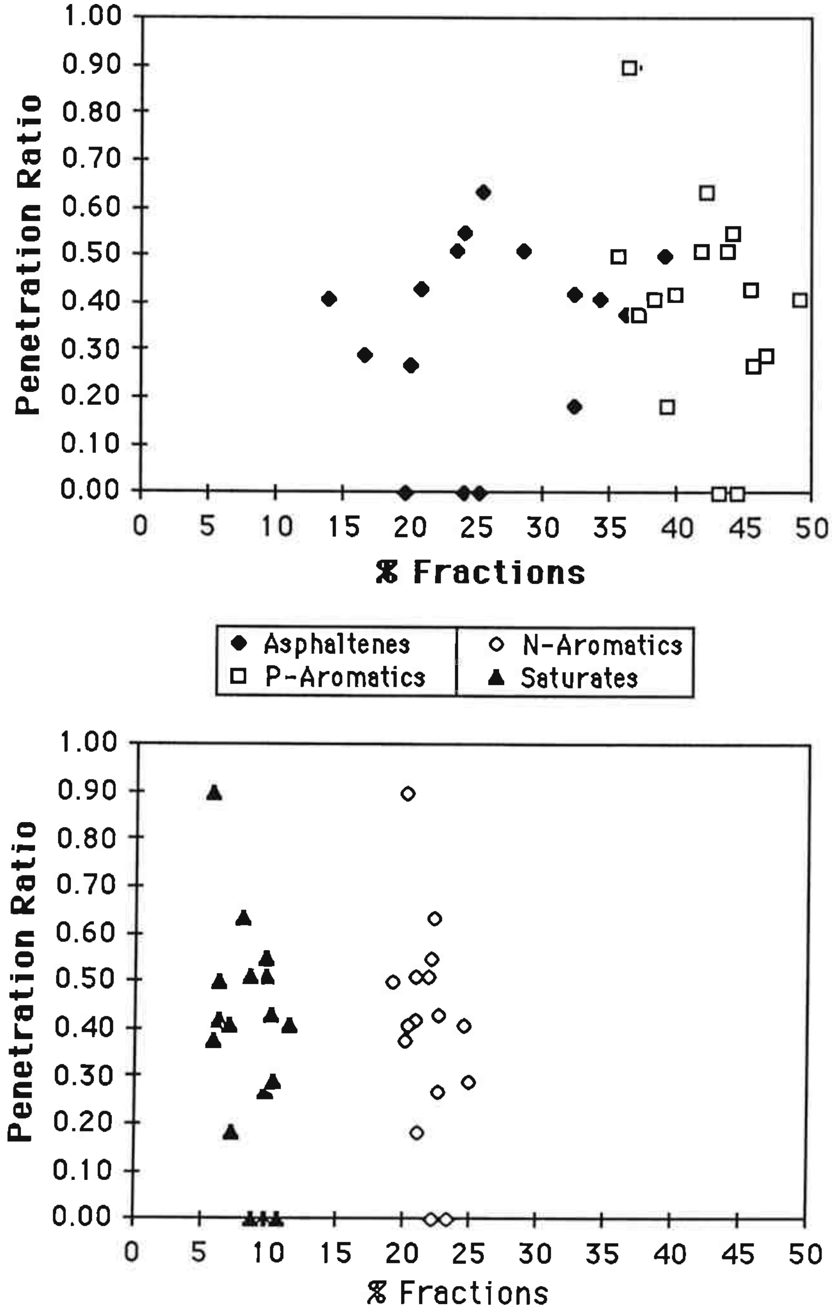

Figure 3.24: Penetration Ratio vs Chemical Fractions.
Recovery Method-A.

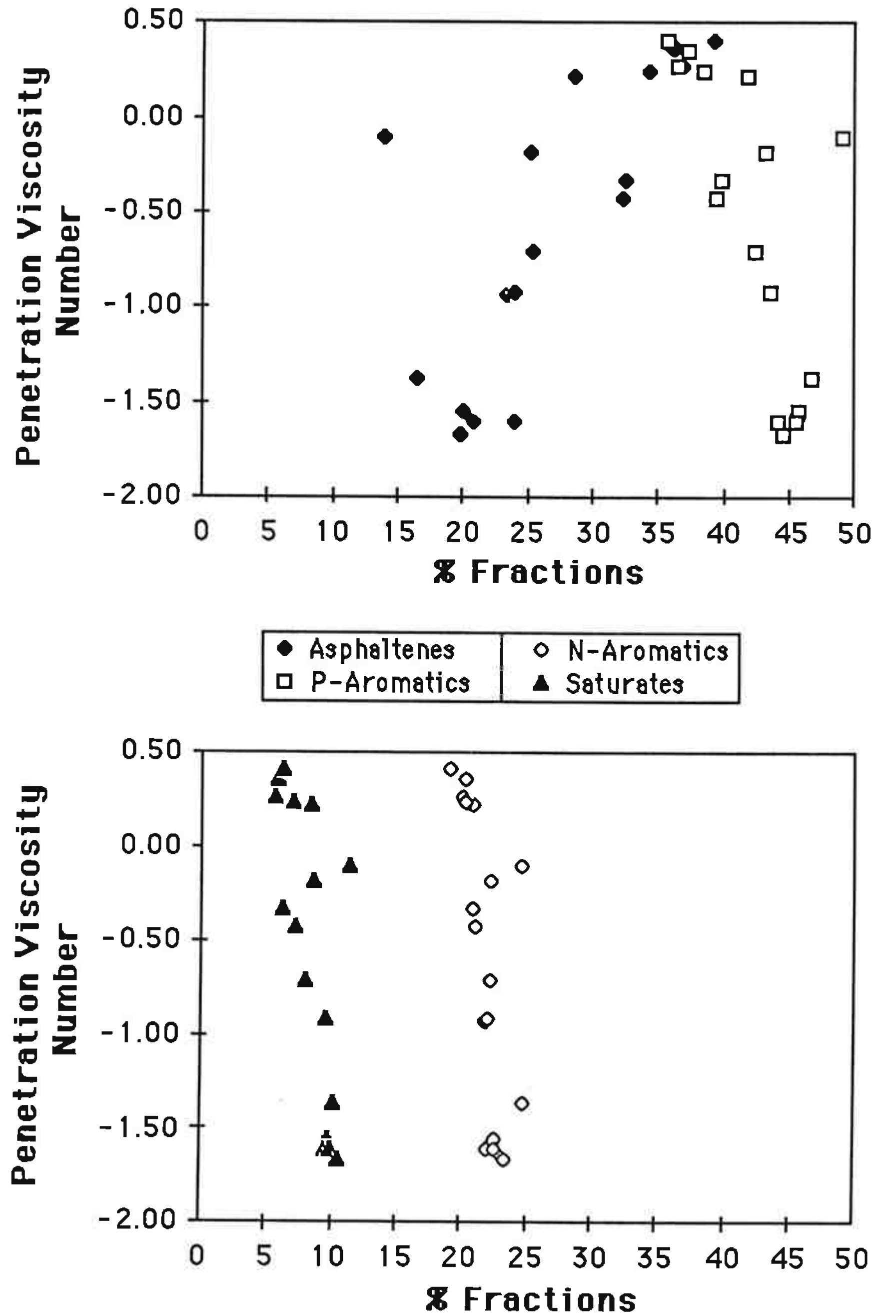

Figure 3.25: Penetration Viscosity Number vs Chemical Fractions. Recovery Method-A.

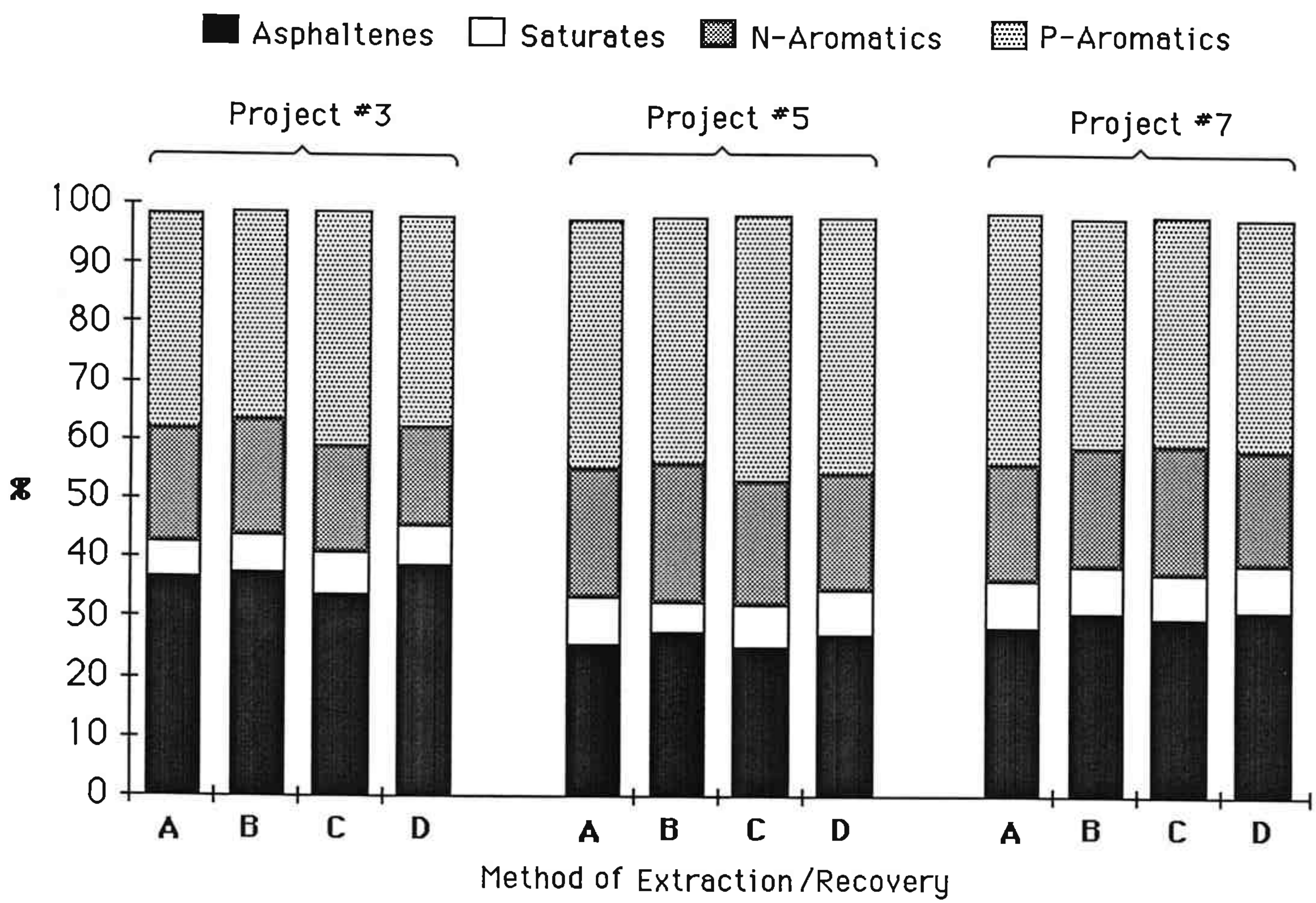

Figure 3.26: Comparison Between Four Extraction/Recovery Procedures

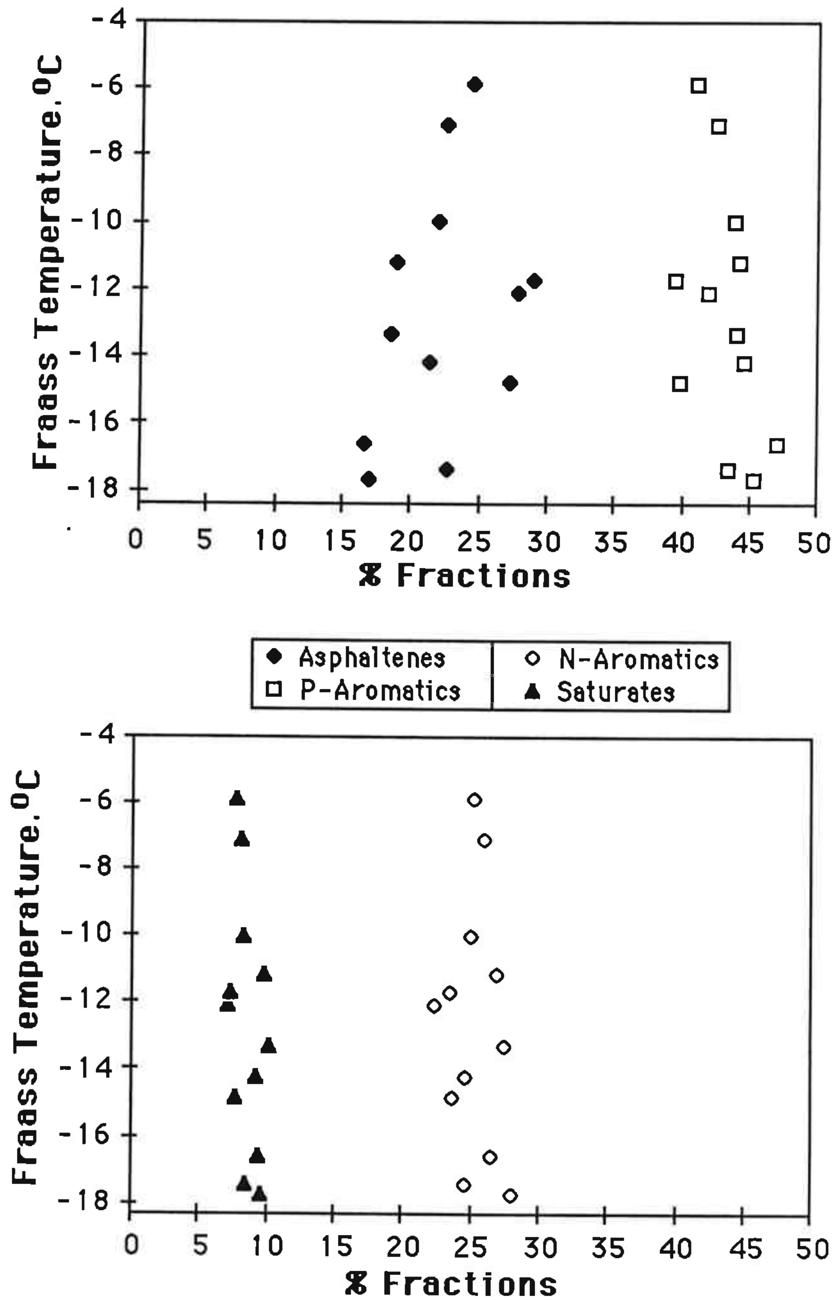

Figure 3.27: Fraass Brittle Temperature vs Chemical Fractions. Projects 3,5 & 7.

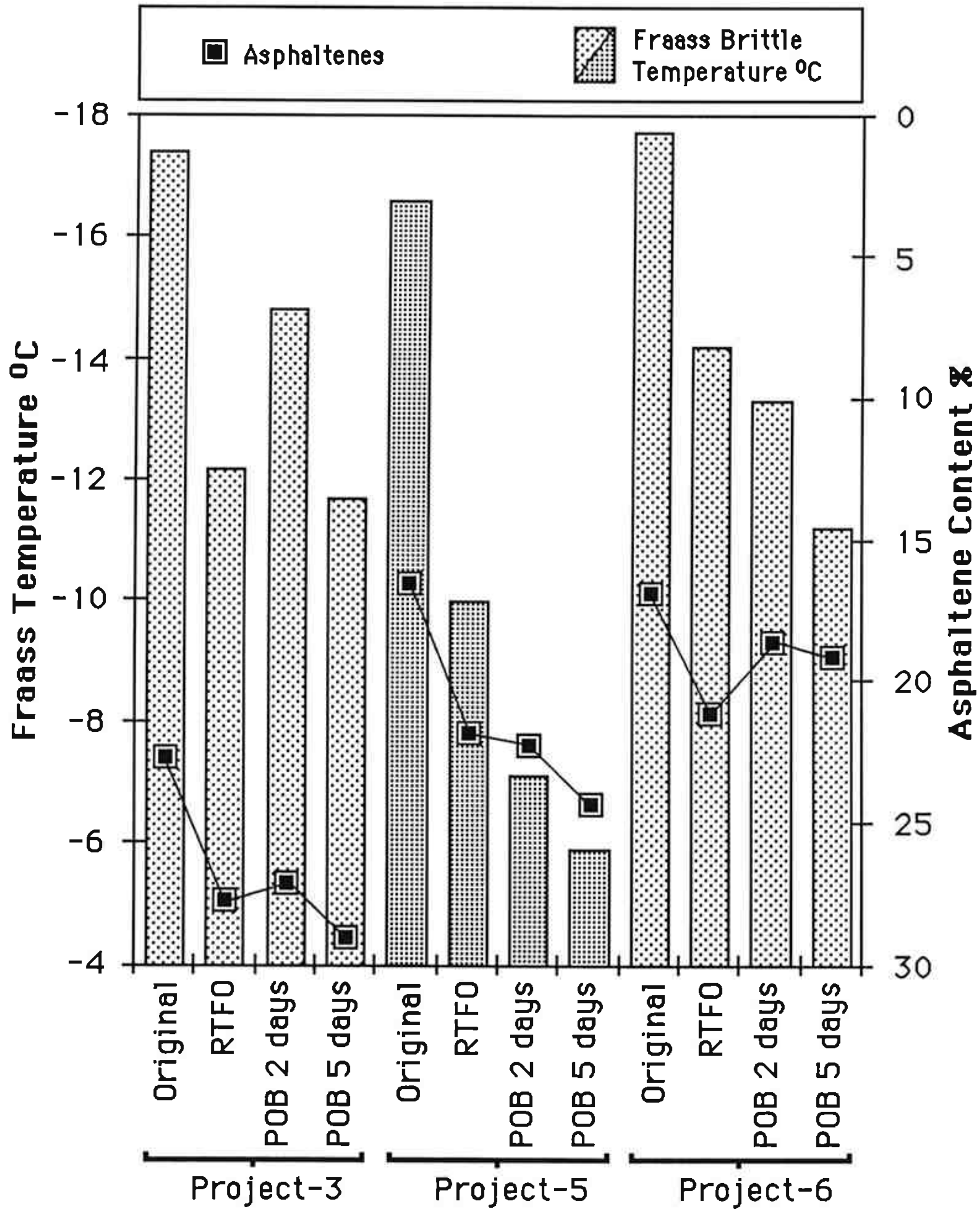

Figure 3.28: Comparison of Results from Aging Tests.

4. CHEMICAL COMPOSITION AS RELATED TO PAVEMENT PERFORMANCE

4.1 Introduction

Pavement performance is a term given to the quality of service that a pavement structure gives during its service life. There are numerous factors that contribute to the deterioration of a pavement structure and the subsequent reduction in its performance. In summary, the following factors determine the overall performance characteristics of an asphalt pavement and its life expectancy:

a) Materials

- Asphalt initial properties and asphalt types
- Aggregates and asphalt-aggregate affinity
- Additives

b) Mixing

- Cold, hot
- Mixing plants

c) Construction

- Transportation and compaction
- Quality control

d) Mix Design

- Dense, open-graded, Macadam
- Asphalt content, air voids, film thickness

e) Pavement Structure

- Pavement thickness
- Base, subbase, and subgrade strength

f) Traffic

- Loads, number of load repetitions, and type of loads

- Speed
- Tire characteristics

g) Environment

- Extreme temperatures
- Water and oxidative agents
- Spring thaw

h) Time

i) Maintenance techniques and frequency of maintenance

All eight projects chosen in the present research combined many of the above factors in a rather random arrangement where it is almost impossible to isolate any detrimental element and subsequently to relate performance to the composition of the asphalt used. Further, a pavement structure may show different types of distress at the same time and each distress mode may be caused by the same or a different factor. Another problem in relating pavement performance to any of the above factors is the difficulty in compiling all the construction and field data, particularly when an asphalt pavement has been in service for a long period of time and it has been exposed to a wide range of traffic and environmental conditions (Table 2.1).

4.2 Relation to Pavement Performance

To search for any relationship between chemical composition and pavement performance, the following observations were considered:

a) Most types of distress that shorten the life of an asphalt pavement are related to an increase in hardening of the asphalt material, reducing its ability to absorb energy (brittleness) and causing it to become more sensitive to failure at low temperatures and/or normal highway strains and stresses (aging).

b) In all eight asphalts studied in the present research, an increase in hardening was associated with an increase in asphaltene content. Further, from the analysis made in sections 3.4 and 3.5, it was observed that the asphaltene content was the only chemical component that consistently showed some type of deviation with changes in physical properties in all eight projects. Thus, as a preliminary attempt to relate asphalt composition to pavement performance, only the asphaltene fraction was used in the present analysis. Another reason for choosing the asphaltene fraction was that there appears to be more consensus among researchers in this area on the characteristics of this generic fraction than for the other three fractions (17,18,19).

With these observations in mind, relative aging parameters were developed before attempting an analysis of the data. The relative aging of asphalt was expressed in terms of asphaltene ratio between original asphalt and aged asphalt (Table 3.3). The following ratios were calculated:

$$RA1 = \frac{\text{\% Asphaltene Content Original Sample}}{\text{\% Asphaltene Content After RTFO}} \tag{4.1}$$

$$RA2 = \frac{\text{\% Asphaltene Content Original Sample}}{\text{\% Asphaltene Content Recovered Asphalt from Surface}} \tag{4.2}$$

$$RA3 = \frac{\text{\% Asphaltene Content Original Sample}}{\text{\% Asphaltene Content Recovered Asphalt from Base}} \tag{4.3}$$

A fourth ratio was also calculated to determine the relative aging between the surface and base:

$$RA4 = \frac{\text{\% Asphaltene Content Recovered Asphalt from Base}}{\text{\% Asphaltene Content Recovered Asphalt from Surface}} \quad (4.4)$$

For projects 3, 5, and 7, two more ratios were calculated to compare the relative aging of the pressure oxygen bomb with the RTFO and field aging.

$$RA5 = \frac{\text{\% Asphaltene Content Original Sample}}{\text{\% Asphaltene Content After POB - 2 Days}} \quad (4.5)$$

$$RA6 = \frac{\text{\% Asphaltene Content Original Sample}}{\text{\% Asphaltene Content After POB - 5 Days}} \quad (4.6)$$

The aging ratios for all projects are summarized in Table 4.1. Several important aspects of the aging undergone by the asphalt in service and in the laboratory are shown as related to chemical compositional changes:

a) The Rolling Thin Film Oven Test (RTFO) was always less severe than field conditions when compared to the exposed section of the pavement structure but was not always less severe when compared to the base section of the same pavement structure. This is an important aspect to consider since some structural design procedures are based on the stresses and strain developed in the bottom part of the structural section of pavement and should use an asphalt stiffness based on the consistency of the asphalt as it ages in the pavement. Without better information, the asphalt could be assumed to have similar properties to those obtained after RTFO.

b) Table 4.1 also includes the POB asphaltene aging ratios of projects 3, 5, and 7. Comparing these ratios with field ratios shows that the POB, in general, does not simulate field aging in terms of the percent change of asphaltenes.

Projects 3, 5, and 7 have different ages and are located in different environments. Thus, it is doubtful that one aging procedure would simulate all types of field aging. However, the POB test may be adjusted (temperature, oxygen pressure, and aging time) so that if the state (or any other large area) is subdivided into appropriate zones, the POB test may be "calibrated" to represent field aging conditions of zones of similar environment and traffic conditions. Similarly, the POB could be used to cycle oxygen and moisture conditioning, if the environment was to cause such moisture damage (3).

c) The relative aging between surface and base was given as RA4 (Table 4.1). Low ratios may indicate some type of severe aging on the surface of the pavement due to extreme environment and traffic conditions. A low ratio may also indicate that the type of asphalt used in the surface may not be the same as the one in the base (overlaid pavement structure).

The lowest relative ratios were those for projects 6 and 8. These projects are located in areas where the average annual temperature range is the highest (20); thus, for Oregon this means that they are exposed to lower temperatures in winter and higher temperatures in summer. This may indicate a correlation between aging and temperature, but this should not be regarded as a a definitive finding, since, as explained earlier, there may be other factors that could induce changes in asphalt composition.

d) Laboratory aging ratios and field aging ratios may be correlated to some measurable characteristics of the pavement mix, such as asphalt content, mix air voids, resilient modulus, fatigue life, specific gravity, and others.

In general, very poor correlations were found, indicating again that there are several factors interacting to produce pavement compositional changes. In order to give a more clear picture of the type of relationship found, Figures 4.1 and 4.2 show the "correlation" found between aging ratios (RA1, RA2) versus mix air voids and core resilient modulus, respectively.

Since there are a number of factors influencing pavement performance and in the eight projects under study all these factors are "randomly" presented, a stepwise multi-regression analysis was used to determine which measurable factors have the highest relative contribution in the resilient modulus observed in the field.

For this purpose, NCSS (Number Crunching Statistical System), a statistical package for microcomputers, was used. The measurable dependent variable chosen was the value of resilient modulus (M_r) obtained by testing the top section of core samples in all eight projects. Resilient modulus was used because it was the mixture performance parameter measured for laboratory and field mixture samples. The measurable independent variables included in the analysis were:

1) Air Voids (%)
2) Asphalt Content (%)
3) Thickness of Core (in.)
4) Average Daily Traffic, ADT (#)

5) Percent Trucks (%)

6) Initial Asphaltene Content (%)

7) Asphaltene Aging Ratio, RA1

8) Penetration at 4°C

9) Penetration at 25°C

10) Absolute Viscosity at 60°C (Poises)

11) Kinematic Viscosity at 135°C (cStoke)

12) Penetration Index (Pen 25, Vis 60)

13) Viscosity Temperature Susceptibility (Vis 60, kVis 135)

14) Penetration Viscosity Number (Pen 25, kVis 135)

15) Penetration Ratio (Pen 4, Pen 25)

16) Penetration Aging Ratio (Pen 25, Pen 25 after RTFO)

There are a number of other variables that can be used in the analysis, but the present study will be constrained to the above variables.

Since the computer program can work with seven independent variables at one time, an iterative process was followed to select those groups of variables which gave the highest sequential R-squared and the lowest root mean square (RMSE) and at the same time kept within the selected group only the uncorrelated variables. In using this statistical approach the group with the most significant variables affecting the field resilient modulus can be identified.

The set of variables with the highest relative importance to the others were:

1) Thickness of Core

2) Air Voids

3) Penetration at 25°C

4) Asphaltene Aging Ratio (RA1)

5) Asphaltene Content

6) Penetration Index

7) Penetration at 4°C

Using these variables, a stepwise forward regression analysis was carried out. The stepwise regression analysis produces a multi-regression equation with the highest R-squared by adding one by one the independent variables that contribute best to the correlation. The addition of variables is stopped when R-squared is close or equal to one and/or the RMSE does not decrease more.

Two multi-regression equations were finally obtained. These are given in Tables 4.2 and 4.3. As seen in both tables, an R-squared equal to one was obtained in both cases but the set of independent variables added differed slightly. Both equations may be regarded as correct as there is empirical evidence, for all the variables added, for their contribution to the mechanical properties of asphalt mixes.

In both cases (Tables 4.2 and 4.3) variables were added until R-squared was equal to one; however, an R-squared value equal to 0.99 is still very good. If both selections were to be stopped at that value, both multiregression equations will agree, recognizing thickness, air voids, and penetration at 25°C.

Note: The resilient modulus was measured at 21.5°C using 60 cycles per minute frequency. If the resilient modulus were to be obtained at other temperatures and/or other load frequencies, the multi-regression analysis may have resulted in somewhat different equations.

In both of the regression analyses made above the thickness of the cores (z) has a strong contribution in all of the relationships established for resilient modulus (M_r). The thickness of the core represents a nominal thickness of the top layer of the pavement. The purpose of including the thickness value is that the levels of stresses and strains developed in the pavement structural layer, for the same load, are directly related to the thickness of the pavement. However, the structural capacity of the top layer is also influenced by the structural capacity of the base, subbase, and subgrade.

Measuring resilient modulus (M_r) values of cores in the laboratory ignores the effect of the under layers. The resilient modulus is obtained from Eq. (4.7) where the core thickness (layer thickness = z) has a strong contribution to the final value of M_r,

$$M_r = \frac{cP}{\pi \Delta z} \tag{4.7}$$

where:

c = coefficient function for diameter of core

P = load

Δ = deformation

z = thickness.

Thus, to eliminate the effect of thickness, it may be better to use relative changes of field resilient modulus. Nevertheless, resilient modulus values from the first year of pavement service should be available to compare the data with actual changes in field resilient modulus.

By dropping the thickness variable in the present analysis, it becomes very difficult to select the set of independent variables to arrive at a model which fits the data well. Some difficulties arise due to the fact that no single variable has such strong correlation with resilient modulus as the thickness value. The number of possible regression equations with all the variables included in the present analysis is 2^{16} (two to the power of sixteen). If a stepwise statistical analysis is used, without judgment, important variables might be omitted if they occurred in the sample within a narrow range of values and, therefore, turned out to be statistically not significant.

A new set of regression equations were developed without including the thickness of the pavement to see how other variables may enter into the model. Table 4.4 includes three different regression models for resilient modulus. All these models were built to obtain the highest R^2 possible by including only uncorrelated variables.

The regression models built in the present research are valid only for the eight projects selected in the present research. These models may well represent a large number of pavements, but this cannot be proven because the equations given in Tables 4.2 through 4.4 were built with a relatively small sample population.

To improve the construction of future prediction models, it would be desirable to quantify the pavement conditions by using parameters other than the "absolute" value of the field resilient modulus. Present conditions of the pavement should be expressed in measurable quantities of distress (e.g., Present Serviceability Index, PSI) or present pavement condition should be expressed in terms of relative changes of physical and mechanical properties (e.g., M_r first year/M_r year "n"), as was mentioned earlier. Once a good parameter is selected to represent actual pavement conditions, selection of variables may be made with more confidence.

4.3 Temperature Susceptibility/Fractional Composition as Predictors of Pavement Performance

The analysis presented in the last section underlines the difficulty in relating chemical fractional composition to pavement performance, especially when the projects selected for the study covered a wide range of environments and different construction and highway characteristics.

As a primary attempt to find more direct application of chemical fractional composition and asphalt behavior, the temperature susceptibility parameters may be used since they cover various ranges of temperatures and asphalt physical properties. It has been noted for years that temperature susceptibility of asphalt is associated with possible good or bad behavior of asphalt materials in the field and during construction. For example, asphalts with high temperature susceptibility are more prone to show failures such as cracking or rutting.

The fact that the temperature susceptibility is recognized as a good indicator of asphalt behavior makes it important to visualize how chemical fractionations are related to these temperature susceptibility parameters.

In chapter 3, the relation of each generic fraction to four different temperature susceptibility parameters were discussed and it was observed that all of the susceptibility parameters have some level of sensitivity to the percent change of asphalt fractions. Although this type of approach was more descriptive, it is known that the actual relationship between the parameters studied and fractional composition is more complex. The additive effect of the four generic fractions on temperature susceptibility of asphalt may be better understood by using a nonlinear regression analysis.

Before presenting the regression analysis, two major considerations have to be made in order to understand the limitations of the present analysis.

a) Early work from Corbett (21) in which asphalt fractions were separated and subsequently recombined in different groups gave a good insight into how the interaction of fractions are related to the rheological characteristics of asphalt.

The main conclusions reported in this work (21) may be summarized as follows:

i) The physical properties of each of the four generic fractions are distinctly different from each other.

ii) The fluidity of an asphalt increases by the plasticizing effect of the liquid fractions (saturates and n-aromatics) on the solid fractions (p-aromatics and asphaltenes).

iii) The combination of either the saturates or the n-aromatics with asphaltenes improves the temperature susceptibility and the combination of p-aromatics with asphaltenes makes the temperature susceptibility worse.

iv) Flow resistance is increased by the combination of saturates or n-aromatics with asphaltenes and is decreased by the combination of saturates with polar aromatics.

Further, work presented by Hattingh (22) showed that asphaltene content alone does not provide sufficient data for the evaluation of the quality of asphalt and that it must be used in conjunction with the molecular mass distribution. (See

Interim Report for this study (1) for information on this type of analysis.) This type of approach has also been reported by Jennings et al. (23) and Jennings (24) where it was shown that not only the percentage of asphaltenes but also the size and amount of the large molecular materials which are not necessarily concentrated in the asphaltene fractions play a major role in the performance of an asphalt.

All of these findings underline the importance of recognizing the physico-chemical interactions among different components in order to adequately explain flow properties of asphalt materials.

b) The second consideration to be made is related to the actual temperature susceptibility parameters presently used. The four temperature susceptibility parameters used in the present research have been used in asphalt technology for a number of years despite some controversy among researchers of the appropriate validity of some of them.

When attempting to correlate asphalt composition to temperature susceptibility parameters, it is important to recognize that the four parameters used in the present research are distinctly different. The differences arise from their original derivations and the range of temperature considered in each of them:

1) Penetration Ratio - 4°C to 25°C

2) Penetration Index - 25°C to 60°C (in this research)

3) Viscosity Temperature Susceptibility - 60°C to 135°C

4) Penetration Viscosity Number - 25°C to 135°C (in this research)

Thus, it is expected that the influence of fraction distribution should affect each parameter differently.

The effect of all four generic fractions on temperature susceptibility cannot be studied by using a stepwise regression analysis since, as was shown in section 3.2, all four fractions are correlated to each other. However, generic fractions may be combined together by using various mathematical arrangements (Table 4.5) and the effect of two or more fractions may be represented in a regression equation.

Table 4.5 shows a large number of possible correlations for each temperature susceptibility parameter. Table 4.5 shows the R-squared values for each mathematical combination of generic fractions. The best combination for each temperature susceptibility parameter is printed in bold numbers, but it should be noticed that there are other correlations which also showed higher R-squared values. This suggests that a final model should be adopted based on a larger set of samples since both physical tests (used to calculate temperature susceptibility parameters) and chemical tests (used to obtain the generic fractions) are subject to experimental variations. Thus, a correlation established with a relatively small number of samples may be significantly affected by some outlier results.

Table 4.1: Asphaltenes Aging Ratios

Project #	Laboratory Aging Ratios			Field Aging Ratios		
	RTFO (RA1)	POB2d (RA5)	POB5d (RA6)	Top (RA6)	Base (RA3)	Relative (RA4)
1	0.77	-	-	0.51	0.51	1.01
2	0.77	-	-	0.79	0.75	1.04
3	0.82	0.83	0.78	0.62	0.63	0.98
3a	0.82	-	-	0.58	0.66	0.88
4	0.82	-	-	0.86	0.84	1.03
5	0.76	0.74	0.68	0.65	-	-
5s	0.76	-	-	0.58	-	-
6	0.54	-	-	0.30	0.43	0.70
7	0.80	0.92	0.90	0.60	0.67	0.88
7s	0.80	-	-	0.59	0.70	0.84
8	0.42	-	-	0.29	0.49	0.69

Formulae based on the percentage of asphaltenes content:

(RA1) = (Original)/(RTFO)
(RA2) = (Original)/(Recovered Top)
(RA3) = (Original)/(Recovered Base)
(RA4) = (Recovered Base)/(Recovered Surface)
(RA5) = (Original)/(POB,2days)
(RA6) = (Original)/(POB,5days)

Table 4.2: Stepwise Regression Analysis for Pavement Perfomance. Regression 1.

Y = Resilient Modulus			
Independent Variable Add Xn	**Sequential R-squared**	**RMSE (a)**	**Stepwise Regression Analysis**
X1 = Thickness (in)	.698	188.93	Y = -394.2+599.5(X1)
X2 = Air Voids (%)	.902	188.16	Y = -763.1+567.9(X1)+53.4(X2)
X3 = Penetration at 25 C	.992	36.90	Y = -175.5+520.2(X1)+40.1(X2)-4.07(X3)
X4 = Asphaltene Aging Ratio (RA1)	.997	28.70	Y = -120.1+519.5(X1)+42.0(X2)-3.63(X3) -155.8(X4)
X5 = Penetration Index (PI)	.998	8.80	Y = +296.9+511.6(X1)+36.2(X2)-4.37(X3) -333.1(X4)-137.3(X5)
X6 = Asphaltene Content (%)	1.000	6.53	Y = +158.7+493.6(X1)+39.3(X2)-4.11(X3) -158.7(X4)+165.3(X5)-6.73(X6)

(a) RMSE = Root Mean Square

Table 4.3: Stepwise Regression Analysis for Pavement Perfomance. Regression 2.

Y = Resilient Modulus			
Independent Variable Add Xn	**Sequential R-squared**	**RMSE (a)**	**Stepwise Regression Analysis**
X1 = Thickness (in)	.698	188.93	Y = -394.2+599.5(X1)
X2 = Air Voids (%)	.902	188.16	Y = -763.1+567.9(X1)+53.4(X2)
X3 = Penetration at 25 C	.992	36.90	Y = -175.5+520.2(X1)+40.1(X2)-4.07(X3)
X4 = Asphaltene Content (%)	.996	31.99	Y = -188.8+510.2(X1)+44.5(X2)-3.42(X3) -4.37(X4)
X5 = Penetration at 4 C	1.000	2.30	Y = +51.69+493.6(X1)+43.2(X2)-5.00(X3) -11.52(X4)-5.80(X5)

(a) RMSE = Root Mean Square

Table 4.4: Regression Models for Resilient Modulus

Y = Mr (Resilient Modulus)			
Model #	**Sequential R-squared**	**RMSE (a)**	**Regression Equations**
Model-1	.989	86.50	Mr = 48395+152(X1)-270(X2)+14.78(X4) -11555(X6)-444(X7)
Model-2	.975	131.10	Mr = 174899+216(X1)+125(X2)+269(X3) 11.96(X5)+9681(X9)
Model-3	.987	91.40	Mr = -5289+239(X1)+199(X2)+32.15(X3) -324(X7)+9681(X9)

X1 = Air Voids (5)
X2 = Asphalt Content (5)
X3 = Penetration at 4 C
X4 = Penetration at 25 C
X5 = Absolute Viscosity at 60 C (Poises)
X6 = Viscosity Temperature Susceptibility
X7 = Asphaltenes Content (5)
X8 = Polar Aromatics (%)
X9 = Asphaltene Aging Ratio (RA1)

Table 4.5: Regression Analysis for Asphalt Temperature Susceptibility. R-squared Values.

REGRESSION VARIABLES	PR	PI	VTS	PVN
ASP	0.861	0.825	0.723	0.792
SA	0.739	0.700	0.716	0.679
NA	0.859	0.767	0.698	0.743
PA	0.720	0.789	0.578	0.734
ASP/SA	0.846	0.854	0.667	0.742
ASP/NA *	0.899	**0.888**	0.658	0.791
ASP/PA *	0.861	0.849	0.702	**0.794**
SAxNA *	0.813	0.728	**0.755**	0.736
NAxPA	0.861	0.802	0.712	0.781
ASP/(SA+NA)	0.889	0.884	0.685	0.783
ASPxPA/(SA+NA)	0.892	0.864	0.705	0.782
1/ASP	0.618	0.503	0.670	0.615
1/SA	0.721	0.719	0.629	0.623
1/NA *	**0.910**	0.853	0.676	0.765
1/PA	0.714	0.792	0.563	0.725
(ASP+PA)/(SA+NA)	0.897	0.857	0.701	0.763
SA+NA	0.858	0.779	0.734	0.755
ASPxPA	0.850	0.786	0.739	0.778
ASP+PA	0.854	0.771	0.730	0.751

Best Model *	Regression Equation
PR	= -0.550 + 23.23(1/NA)
PI	= -1.943 + 1.399(ASP/NA)
VTS	= +3.026 + 2.46E-3(SAxNA)
PVN	= -1.947 + 3.146(ASP/PA)

PR = Penetration Ratio
PI = Penetration Index
VTS = Viscosity Temperature Susceptibility
PVN = Penetration Viscosity Number

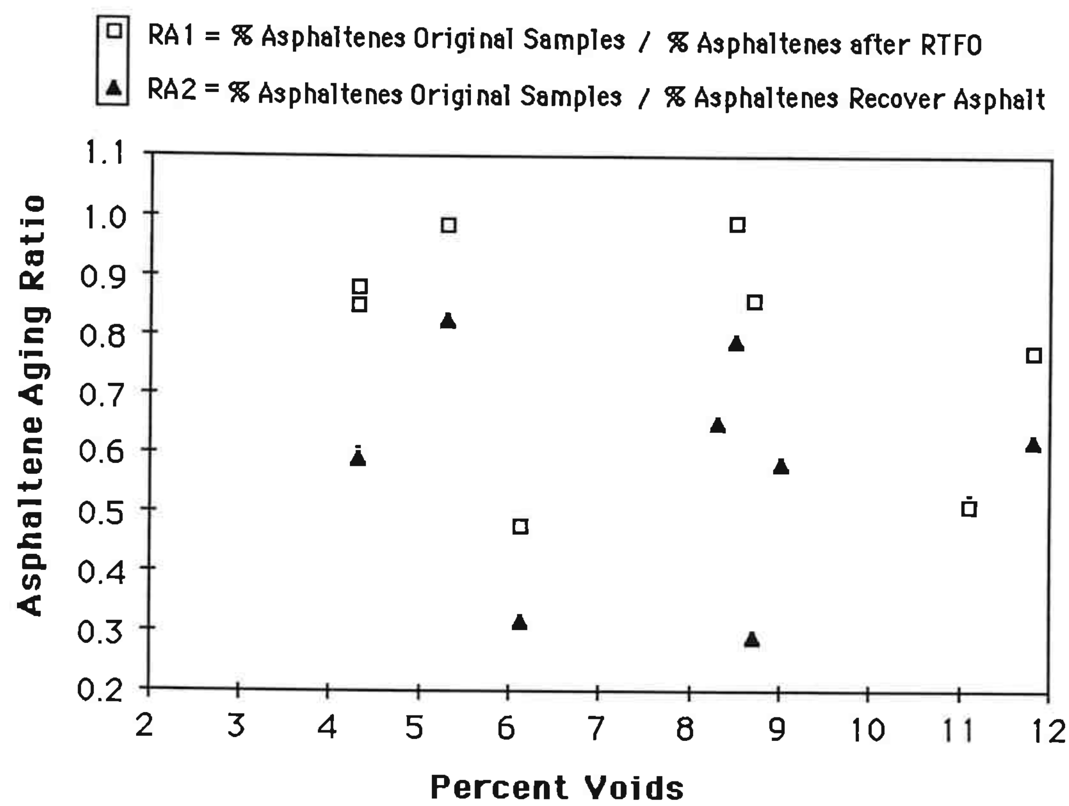

Figure 4.1 : Asphaltene Aging Ratio vs Percent Voids in Mix

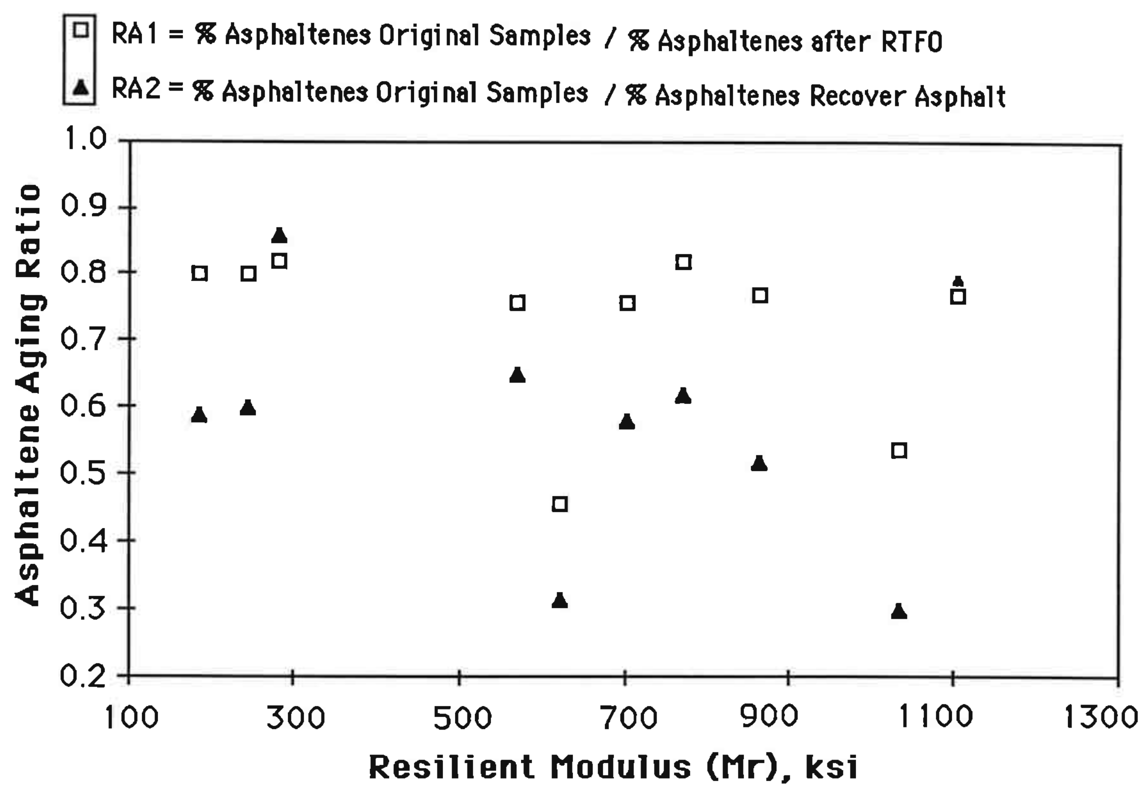

Figure 4.2 : Asphaltene Aging Ratio vs Resilient Modulus

5. CONCLUSIONS AND RECOMMENDATIONS

There were a number of different topics studied and discussed in this report. The main objective was to make use of asphalt chemical composition results obtained through the Corbett-Swarbrick analysis, in conjunction with other laboratory techniques (asphalt physical properties measurement, laboratory aging procedures, and extraction-recovery procedures), and subsequently give an insight into how chemical analysis may be understood and incorporated into the evaluation of asphalt pavement performance.

The conclusions and recommendations are presented here in the same order in which the subjects were presented throughout the report.

5.1 Stored Asphalt

Conclusion. Asphalt samples stored in sealed cans did not show significant variations in their physical properties. Minor variations did not give a clear indication that physical changes were due to aging and these variations were attributed to the reproducibility of the test results.

Recommendation. It would be desirable to write some standard recommendations for the storage of original asphalt samples. These may include, for example, storage conditions such as:

a) Room temperature: 20°C

b) Room conditions: dry

c) Container type: aluminum (to prevent rust)

d) Container size: e.g., one gallon minimum, filled to the top and sealed with the same asphalt to prevent the inclusion of oxygen.

e) Other: such as sampling, initial testing, etc.

These may help to minimize the minor variations which different asphalts may show after long periods of storage.

5.2 Relationship Between Chemical Fractions

Conclusion. The analysis of relationships between chemical components showed that the recovered asphalt did not have the same profile relationships as original plus RTFO samples, indicating that recovered asphalt, after going through the extraction and recovery procedure may be chemically altered and no longer represents the in-place asphalt and/or that the RTFO aging test may not duplicate the chemical changes made by the asphalt under natural weathering and in contact with mineral aggregates.

Recommendation. It is recommended that fractional composition analysis of original and laboratory aged asphalt should be analyzed separately from recovered asphalt when studying relationships between physical properties of asphalt versus chemical composition.

5.3 Relationship Between Chemical Composition and Physical Properties

Conclusion. All physical properties did show some correlation with all four fractions. Better correlations were found at higher temperatures (kinematic viscosity) rather than at lower testing temperature (penetration at 4°C). This may be due to the effect of molecular shape and geometry which are minimized in the higher temperature range. Also, it could be due to the effect of the testing procedures used for different temperatures. At higher temperatures (60 and 135°C) physical properties were measured with a capillary viscometer while at lower temperatures (4 and 25°C) physical properties were measured with a penetrometer. Penetrometers are regarded as less accurate instruments and do not measure fundamental properties of non-Newtonian liquids. There is no control over the shear rate and shear stress applications which are two important variables which affect asphalt physical response in the non-Newtonian region of flow (approximately below 60°C).

Recommendation. It was considered difficult to arrive at recommendations with regard to requirements of chemical composition and asphalt physical properties. It was found from the literature and actual experience that the interaction of two or more components, as well as other molecular properties, greatly influenced the rheological behavior of asphalt. Nevertheless, this research showed consistently that for individual asphalts or groups of different asphalts, increases in viscosity in the higher temperature range (Newtonian flow range) were associated with increases in asphaltene fractions.

5.4 Relationship Between Chemical Composition and Temperature Susceptibility Parameters

Conclusion. Relatively good relations were found between fractional composition and temperature susceptibility. Temperature susceptibility index was categorized between those which measured susceptibility at lower temperatures (PR and PI) and those which measured susceptibility at higher temperatures (VTS and PVN). Better correlations were found for the PR and PI indexes (penetration ratio and penetration index) than for VTS and PVN (viscosity temperature susceptibility and penetration viscosity number). A statistical regression analysis showed that the four susceptibility indexes used were distinctly different and that fractional composition had entirely different effects on all four indices used.

Recommendations. The above temperature susceptibility parameters are not comparable because they measured property indices in a different range of temperature where the chemical components of asphalt have different influence.

Regression models may be built, based on fractional composition, to predict temperature susceptibility but a larger set of samples is needed to account for laboratory testing variations.

5.5 Response of Individual Asphalts

Conclusion. This research showed that a certain level of generalization of rheological and chemical behavior on original and aged asphalt may be made by studying a relatively small group of asphalts. However, analysis of individual asphalts showed that different asphalts do behave differently and do age differently. The different types of behavior shown by all the samples when changing from original to aged materials suggest that, to better characterize asphalt properties after aging, more than one aging condition should be studied. For example, asphalt samples should be aged at three or four different RTFO conditions and after measuring physical and/or chemical properties, the rate of changes in measured properties should be compared among the different asphalts subjected to study. Measuring absolute changes of asphalt properties based on one aging condition may not reflect the overall aging behavior of this material.

5.6 Extraction and Recovery Procedure

Conclusion. Asphalt extracted and recovered from core samples did show a different chemical profile than the original asphalt. Thus, care is advised when using data from recovered and original asphalts together.

The four methods that were used to extract and recover asphalt samples did not give consistent results and both physical and chemical properties measured after recovery were significantly different.

Recommendation. It is recommended, for consistency, that the Oregon State Highway Division Laboratory continue to use the same extraction/recovery procedure (Method-A) which they have used to date.

If interest persists in using the cold vacuum extractor and/or a Roto-evaporator for recovery, more research is recommended to produce compatible results or to establish correlations.

5.7 Fraass Test and POB

Conclusion. Insufficient data was gathered for meaningful conclusions regarding asphalt low temperature behavior and its relation to asphalt composition. With the little data available (from projects 3, 5, and 7), it was observed that generally asphalt composition did not show great dependency with the Fraass brittle temperature, suggesting that other molecular properties (e.g., molecular size, molecular structuring, and molecule geometry) may be more important than fraction composition as related to low temperature behavior.

Analyzing by individual asphalts (3, 5, and 7), it was observed that asphaltene content increases with aging in a relatively similar proportion to the increase in Fraass temperature. However, the initial proportion of asphaltenes on all three projects was not related to the total amount of laboratory aging.

The POB test, in general, did not simulate field aging test in terms of the percent change of asphaltenes. However, the POB showed enough flexibility that it may be adjusted to simulate asphalt aging conditions of zones with different types of environments. The POB did cause greater change than RTFO.

Recommendation. More testing is recommended for the POB device with a larger number of samples. This will permit the following of a statistical analysis rather than a descriptive discussion of results.

5.8 Field Performance

Conclusion. It was difficult to relate field performance to asphalt composition. The eight projects chosen in the present research combined many of the detrimental aging factors in a rather "random" arrangement and it was impossible to isolate any detrimental element and subsequently relate performance to the composition of the asphalt used.

Four chemical aging ratios were defined to describe aging susceptibility. Relative aging between laboratory and field environment was compared and none of the aging laboratory procedures used were found to be more severe than field conditions.

Relative aging from top and base of core samples was different. However, future studies may be improved if, instead of cutting the top surface to a depth of 1.5 to 2.0 inches, this is done to a depth of half of an inch so that the aging experienced by the wearing surface is distinguished from the aging experienced by the structural section.

Very poor correlation was found between chemical aging ratios and mixture resilient modulus, suggesting that pavement mix performance is dependent upon a number of other factors (listed in Chapter 4).

All the environmental factors listed in Chapter 4 were used in a stepwise statistical regression analysis and correlated to resilient modulus of core samples taken from the field. Three multi-regression equations were obtained with sequential R-squared greater than 0.9. The combined effect of the set of variables given in Table 4.5 represents a prediction model of the resilient modulus for the group of projects studied.

Recommendations. To improve the construction of future prediction models, it would be desirable to quantify pavement conditions by using parameters other than the "absolute" value of the field resilient modulus. Present conditions of the pavement should be expressed in measurable quantities of distress (e.g., Present Serviceability Index, PSI) or by measuring relative changes of physical and/or mechanical properties of pavement immediately after construction and after being in service a number of years (e.g., M_r first year/M_r year "n"). Once a good parameter is selected and used consistently, selection of independent variables to predict pavement performance may be made with more confidence.

6. SUMMARY

This research study included eight different highway projects. An analytical chemical test procedure was used to determine fractional composition of asphalt pavement materials before and after construction. The test procedure was similar to that developed by Corbett and Swarbrick. The application of this test in conjunction with several standard physical tests provided much insight into the behavior and properties of asphalt pavement materials.

Major findings were:

1) Asphalt samples stored in sealed cans did not show significant variations in their physical properties. Minor variations did not give a clear indication that physical changes were due to aging and these variations were attributed to the reproducibility of the test results.

2) The analysis of relationships between fractional components showed that the recovered asphalt did not have the same profile as original plus RTFO samples, indicating that recovered asphalt, after going through the extraction and recovery procedure may be chemically altered and no longer represents the in-place asphalt and/or that the RTFO aging test may not duplicate the changes made by the asphalt under natural weathering and in contact with mineral aggregates.

3) All physical properties did show some correlation with all four fractions. Better correlations were found at higher temperatures (kinematic viscosity) rather than at lower temperatures (penetration at 4°C). This may be due to the effect of

molecular shape and geometry which are minimized in the higher temperature range, and due to the effect of the testing procedures used for different temperatures.

4) Relatively good relations were found between fractional composition and temperature susceptibility. Better correlations were found for the PR and PI indices (penetration ratio and penetration index, low temperature range) than for VTS and PVN (viscosity temperature susceptibility and penetration viscosity number, high temperature range). Regression analyses showed that the four indices used were distinctly different and that fractional composition had entirely different effects on all four.

5) A certain level of generalization of rheological and chemical behavior on original and aged asphalt was possible by studying a relatively small group of asphalts. However, analysis of individual asphalts showed that different asphalts do behave differently and do age differently. The different types of behavior shown by all samples when changing from original to aged materials suggest that, more than one aging condition could be studied. For example, asphalt samples should be aged at three or four different RTFO conditions and the rate of changes in measured properties compared among the different asphalts. Measuring absolute changes of asphalt properties based on one aging condition may not reflect the overall aging behavior.

6) Asphalt extracted and recovered from cores showed a different composition profile than the original asphalt. Thus, care is advised when using data from recovered and original asphalts together. The four methods used to extract and recover asphalt samples did not give consistent results and both physical properties and composition measured after recovery were significantly different.

7) Insufficient data was gathered for meaningful conclusions regarding asphalt low temperature behavior and its relation to asphalt composition. With the little data available (from projects 3, 5, and 7), it was observed that generally asphalt composition did not show great dependency with the Fraass brittle temperature, suggesting that other molecular properties (e.g., molecular size, molecular structuring, and molecule geometry) may be more important than fractional composition as related to low temperature behavior. It was observed that asphaltene content increases with aging in a relatively similar proportion to the increase in Fraass temperature. However, the initial proportion of asphaltenes on all three projects was not related to the total amount of laboratory aging.

8) The POB test, in general, did not simulate field aging, in terms of the percent change of asphaltenes. However, the POB showed enough flexibility that it may be adjusted to simulate asphalt aging conditions of zones with different types of environments. The POB did cause greater change in composition than RTFO.

9) There was not a strong correlation of pavement performance with an individual property. Rather, pavement performance statistically relates to many physical and chemical properties of asphalt. However, the physical and chemical properties that may enter into the correlation depend on which parameters are used to evaluate pavement conditions.

The most significant recommendations of this study are:

1) It is recommended that fractional composition analysis of original and laboratory aged asphalt should be analyzed separately from recovered asphalt when studying relationships between physical properties of asphalt versus chemical composition.

2) The temperature susceptibility parameters were not comparable because they measured property indices in a different range of temperature where the components of asphalt have different influences. Regression models may be built, based on fractional composition, to predict temperature susceptibility but a larger set of samples is needed to account for laboratory testing variations.

3) It is recommended, for consistency, that the Oregon State Highway Division Laboratory continue to use the same extraction/recovery procedure (Method-A) which they have used to date. If interest persists in using the cold vacuum extractor and/or a Roto-evaporator for recovery, more research is recommended to produce compatible results or to establish correlations.

4) More testing is recommended for the POB device with a larger number of samples. This will permit a statistical analysis rather than a descriptive discussion of results.

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