



400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096-0001 U.S.A

HFC - 134a LUBRICANT STUDY

An SAE Cooperative Research Report
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**SAE COOPERATIVE
RESEARCH PROGRAM**

HFC-134a LUBRICANT STUDY



SAE COOPERATIVE RESEARCH PROGRAM

HFC-134a LUBRICANT STUDY

FINAL REPORT

**Prepared for: SAE International
400 Commonwealth Drive
Warrendale, PA**

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November 6, 1992

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1.0 SAMPLES AND SAMPLE CHARACTERIZATION

Two liter samples of each lubricant were submitted to SAE, which were coded and forwarded for inclusion in the program. The lubricants are numbered consecutively in this report, beginning with LS-001 and ending with LS-020; samples LS-002 and LS-018 were cancelled after initiation of the program and are therefore omitted from the sequence.

Lubricants were stored in tightly capped containers during the course of the program and samples were withdrawn from these to carefully avoid contamination of the sample bottle. Some tests required withdrawing an amount slightly larger than actually consumed; any remaining lubricant was discarded and not returned to the sample bottle. The total amount of time that the samples were exposed to atmospheric conditions was kept to the bare minimum to avoid moisture absorption.

Two thirty-pound cylinders of HFC-134a were commercially purchased from DuPont and were dedicated to this program. Each was analyzed by gas chromatography prior to use and was found to contain no significant impurities.

Basic property information requested from the suppliers included:

- Viscosity at 40°C (104°F)
- Viscosity Index
- Moisture Content (as shipped)
- Water Solubility
- Moisture Absorption
- HFC-134a Miscibility
- Sealed Tube Stability

This information was, in most cases, submitted with the lubricant sample, and SAI performed the following tests on the six indicated samples:

<u>Sample</u>	<u>Tests Performed by SAI</u>
LS-003	sealed tube stability
LS-006	sealed tube stability
LS-008	sealed tube stability and miscibility
LS-009	sealed tube stability and miscibility
LS-011	sealed tube stability
LS-015	sealed tube stability

Tables 1, 2 and 3 which follow summarizes this basic property information. Frequently, more data was furnished than is reported in Table 1 (for example, miscibility data and moisture absorption data were often given as a graph, rather than a table), but it is the intent to summarize this data into a concise format, rather than report all data which was received.

Sample	Viscosity, cst at 40C(104F)	Viscosity Index	Moisture ¹ as shipped	Moisture ² at saturation	Water solubility
LS-001	100.0	220	238	20,000	NO
LS-003	96.1	96	90	N/A ³	No
LS-004	92.6	90	150	1,700	No
LS-005	134.0	114	36	3,000	No
LS-006	124.0	97	190	300	NO
LS-007	140.9	124	218	N/A	No
LS-008	102.4	127	6	N/A	No
LS-009	79.1	N/A	N/A	N/A	No
LS-010	97.0	97	35	1,500	No
LS-011	128.0	91	190	1,200	No
LS-012	140.6	150	833	N/A	No
LS-013	99.2	120	255	N/A	No
LS-014	76.5	162	32	8,000	No
LS-015	125.0	84	100	1,200	No
LS-016	146.6	111	205	N/A	NO
LS-017	154.0	139	48	6,600	No
LS-019	95.0	109	40	2,420	NO
LS-020	120.6	182	172	11,700	NO

¹Units are ppm.

²Units are ppm. This column is provided as a very rough comparison due to the wide variation of test conditions (surface area to depth ratio was not specified, ambient temperature and relative humidity vary, time to the end of test varies). See Appendix A for complete supplier data, Section 2.0 for one-week data.

³N/A = Not Available.

**TABLE 1: SUPPLIER BASIC PROPERTY DATA -
VISCOSITY, MOISTURE AND WATER SOLUBILITY**

PHASE SEPARATION TEMPERATURES IN DEGREES CELSIUS

Sample	<u>10% Lubricant</u>		<u>20% Lubricant</u>		<u>30% Lubricant</u>	
	<u>Lower</u>	<u>Upper</u>	<u>Lower</u>	<u>Upper</u>	<u>Lower</u>	<u>Upper</u>
LS-001	< -50	39	< -50	42	< -50	44
LS-003	-14	N/A	-5	N/A	-1	N/A
LS-004	-40	> 60	-33	> 60	-34	> 60
LS-005	14	N/A	22	61	20	N/A
LS-006	-25	> 75	-25	> 75	-30	> 75
LS-007	5	N/A	10	N/A	-10	N/A
LS-008	-48	55	< -60	76	< -60	91
LS-009	-20	91	-15	93	-16	> 93
LS-010	-34	> 60	-30	> 60	-33	> 60
LS-011	-70	> 75	-55	> 75	-65	> 75
LS-012	< -60	60	< -60	21	< -60	32
LS-013	< -67	82	< -67	82	< -67	90
LS-014	N/A	N/A	N/A	N/A	N/A	N/A
LS-015	-20	> 75	-25	> 75	-25	> 75
LS-016	-29	> 82	-4	> 82	-26	> 82
LS-017	N/A	N/A	N/A	N/A	N/A	N/A
LS-019	-65	> 70	-60	> 70	-65	> 70
LS-020	< -40	67	< -40	63	< -40	70

**TABLE 2: SUPPLIER BASIC PROPERTY DATA - MISCIBILITY
OF NEAT LUBRICANTS WITH HFC-134a**

Sample	Color Change		Flouride Ion Generated, ppm	TAN ¹		Visual Inspection
	From	To		From	To	
LS-001	slight yellowing		< 4	N/A	N/A	Cu, Al and Fe clean and bright.
LS-003	2.5 ²	4.5	< 5	N/A	N/A	Al and Fe clean and bright. Cu black.
LS-004	no discoloration		N/A	N/A	N/A	Oil bright & clear. Cu, Al, Fe clean.
LS-005	0-0.5 ³	0.5-1	N/A	0.022	0.056	No change in Al or Fe. Slight tarnish of Cu in gas phase.
LS-006	2.5 ²	3.0	< 4	N/A	N/A	Al and Fe clean and bright. Cu slightly tarnished.
LS-007	clear	golden yellow	N/A	N/A	N/A	Slight dulling of metals in liquid.
LS-008	4.0 ²	4.0	< 3	N/A	N/A	Cu, Al and Fe clean and bright. No dep.
LS-009	2.0 ²	2.0	< 1	N/A	N/A	Al and Fe clean and bright. Cu tarnish.
LS-010	no change		N/A	N/A	N/A	No indication of R/L decomposition.
LS-011	2.5 ²	2.5	< 1	N/A	N/A	Cu, Al and Fe clean and bright.
LS-012	no change		N/A	N/A	N/A	No visible changes in metals.
LS-013	<0.5 ³	<0.5	N/A	N/A	N/A	Slight discoloring of Fe. Etching of Cu wire.
LS-014	no change		N/A	N/A	N/A	Cu, Al and Fe show no color change.
LS-015	2.0 ²	2.0	< 3	N/A	N/A	Cu, Al and Fe clean and bright.
LS-016	clear	golden yellow	N/A	N/A	N/A	Slight dulling of metals in liquid.
LS-017	no change		N/A	N/A	N/A	Cu, Al and Fe show no color change.
LS-019	2.5 ²	2.5	< 3	N/A	N/A	Cu, Al and Fe clean and bright.
LS-020	3.0 ²	3.5	N/A	2.0	2.75	Metals unchanged.

¹TAN = Total Acid Number

²ASTM D1500 Scale

³Color scale unknown

TABLE 3: SUPPLIER BASIC PROPERTY DATA - STABILITY



2.0 HYGROSCOPICITY

Lubricant samples were placed in clean, dry 250 ml beakers, inside diameter 2.5 in., which were filled to 1.875 in. height, giving a surface area to depth ratio of 2.618 in. The samples were placed in a controlled environment at average conditions of 25°C, 50% relative humidity for a period of one week. Samples of each lubricant were taken periodically at a depth of 1 in. beneath the surface of the oil and analyzed by Karl Fischer Model 447 Coulomatic Titrimeter. Results are given in Figures H-1 through H-18, which show the data points along with a smooth curve found by least squares regression. The "as received" moisture content and the moisture after 168 hours exposure is given in Table H-1 below.

<u>Sample</u>	<u>As Received ppm</u>	<u>After 168 hrs ppm</u>
LS-001	83	18,396
LS-003	45	991
LS-004	< 7	1,119
LS-005	< 6	1,186
LS-006	128	1,300
LS-007	47	1,007
LS-008	305	2,408
LS-009	< 6	1,017
LS-010	40	1,118
LS-011	98	1,400
LS-012	420	21,655
LS-013	289	2,460
LS-014	62	5,297
LS-015	118	948
LS-016	116	1,006
LS-017	33	4,971
LS-019	40	2,668
LS-020	123	6,635

TABLE H-1: MOISTURE CONTENT OF LUBRICANT SAMPLES
"AS RECEIVED" AND AT 168 HOURS EXPOSURE

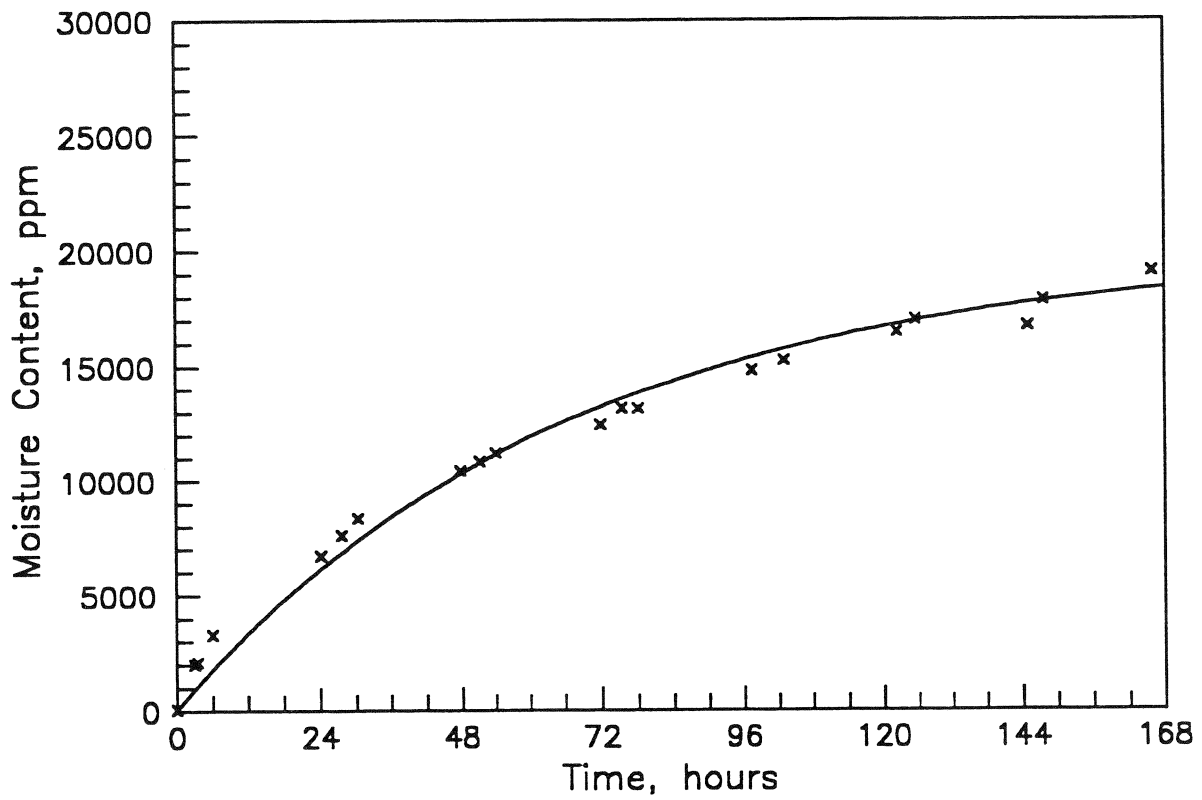
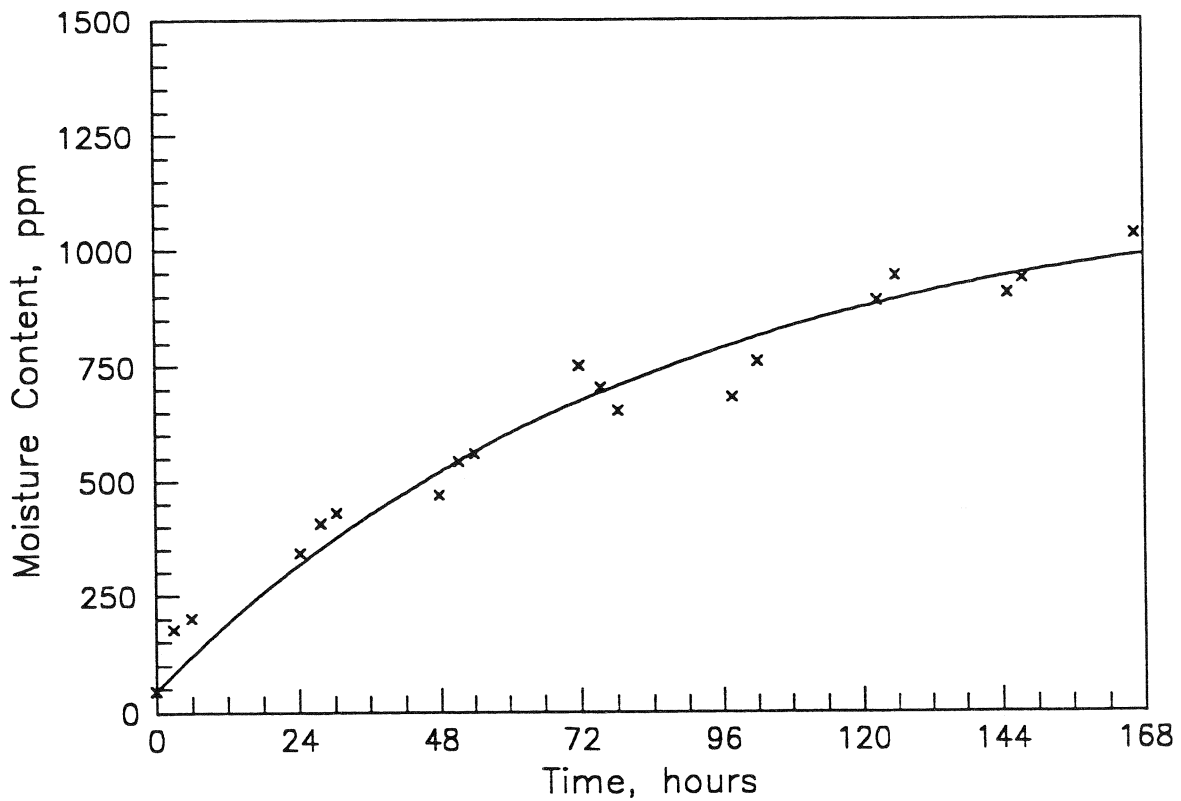
FIG H-1: MOISTURE PICKUP OF SAMPLE LS-001**FIG H-2: MOISTURE PICKUP OF SAMPLE LS-003**

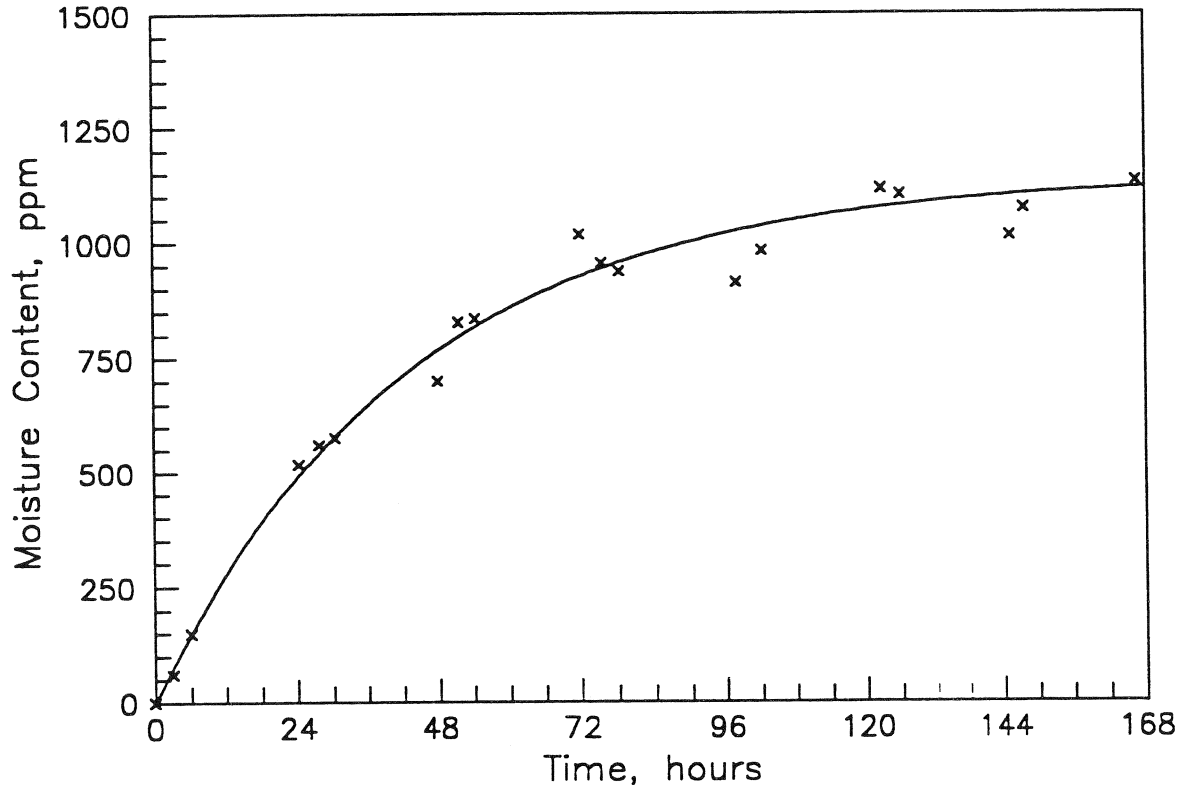
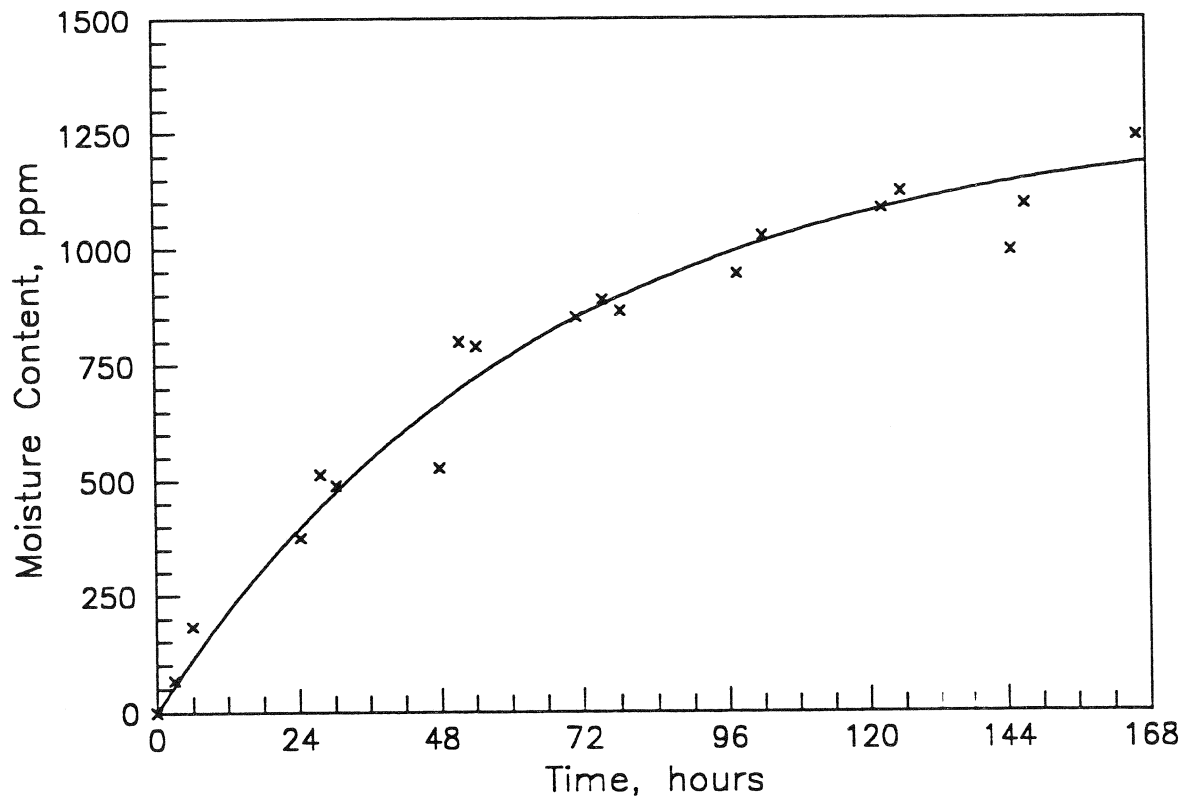
FIG H-3: MOISTURE PICKUP OF SAMPLE LS-004**FIG H-4: MOISTURE PICKUP OF SAMPLE LS-005**

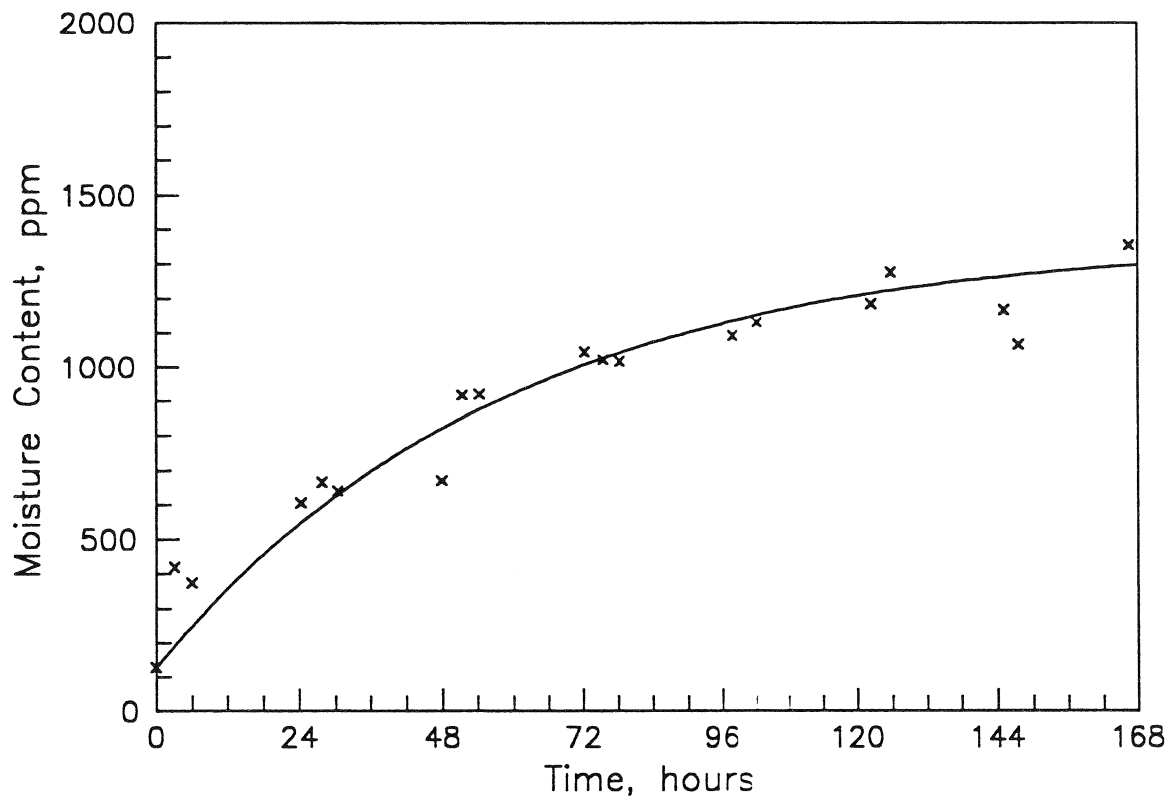
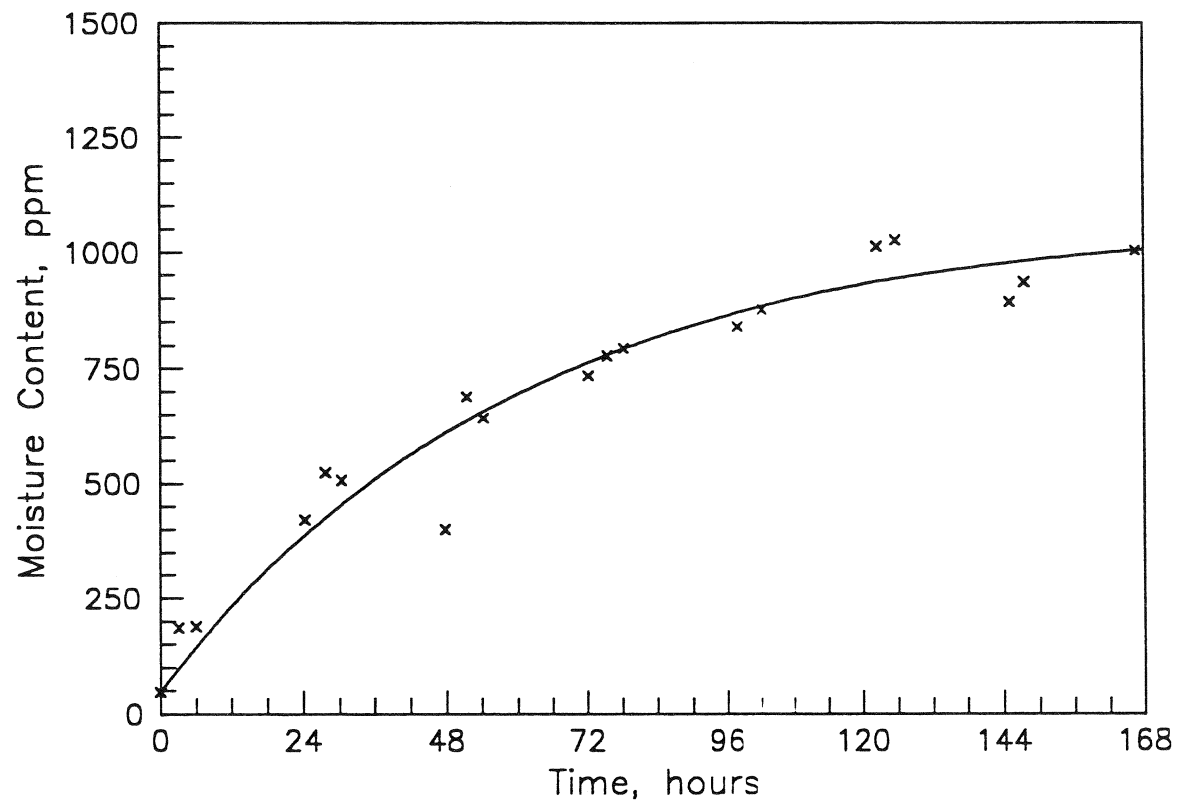
FIG H-5: MOISTURE PICKUP OF SAMPLE LS-006**FIG H-6: MOISTURE PICKUP OF SAMPLE LS-007**

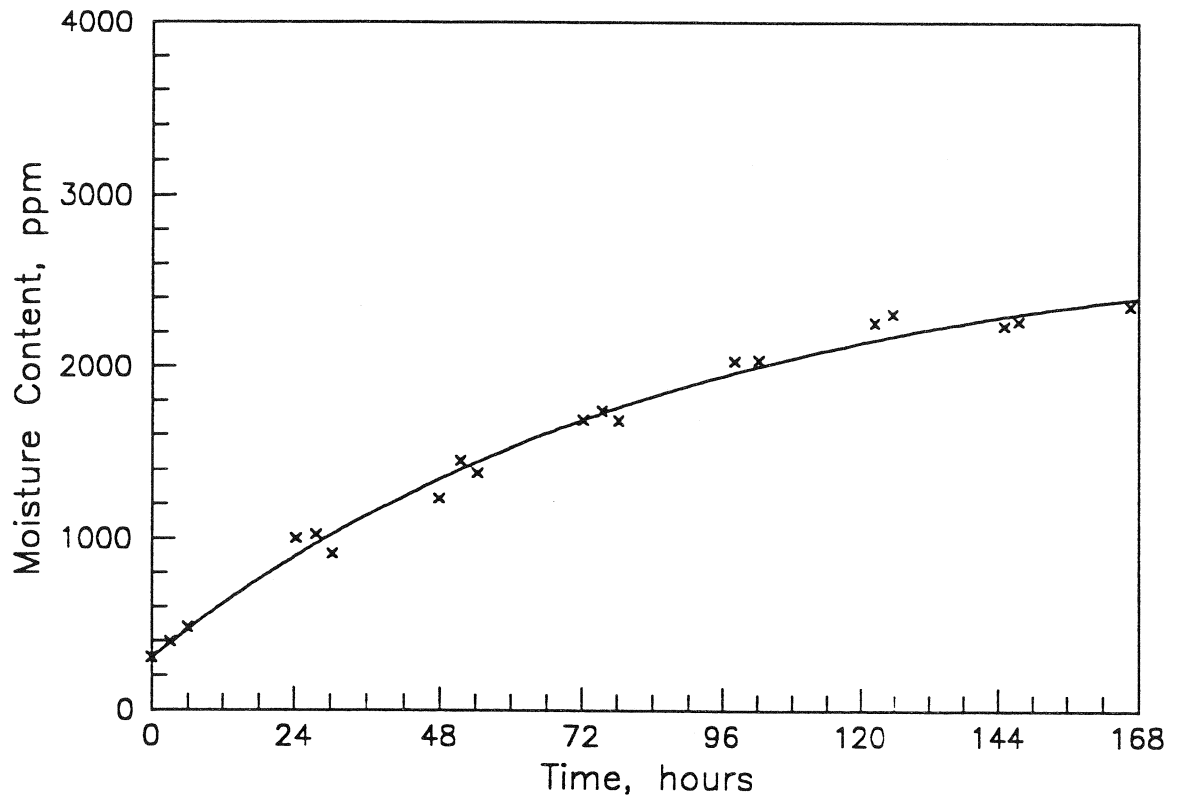
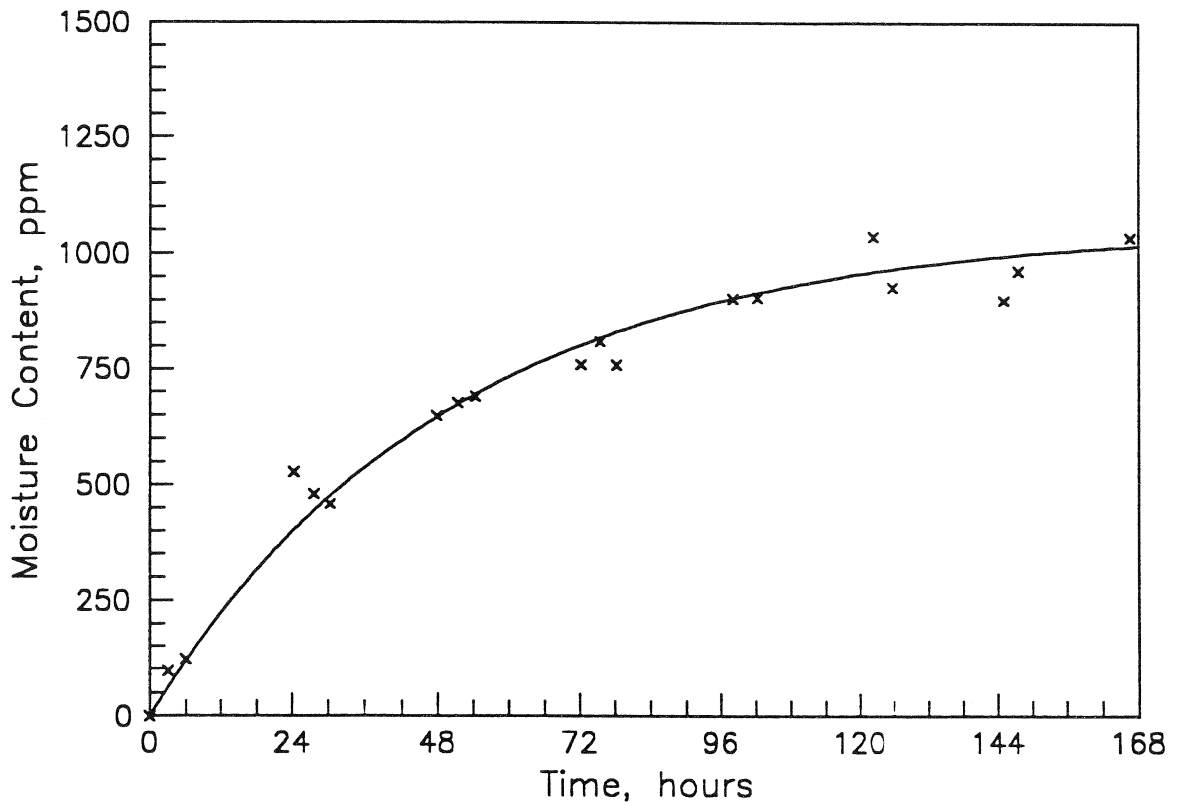
FIG H-7: MOISTURE PICKUP OF SAMPLE LS-008**FIG H-8: MOISTURE PICKUP OF SAMPLE LS-009**

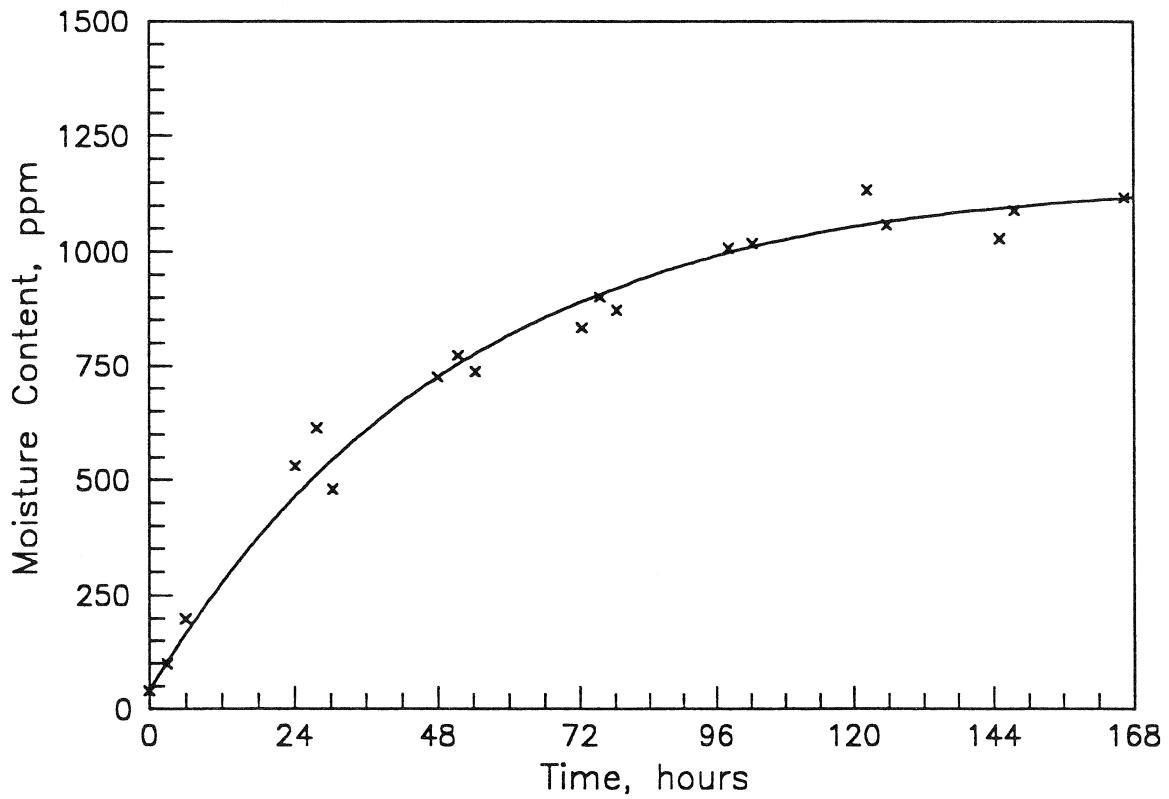
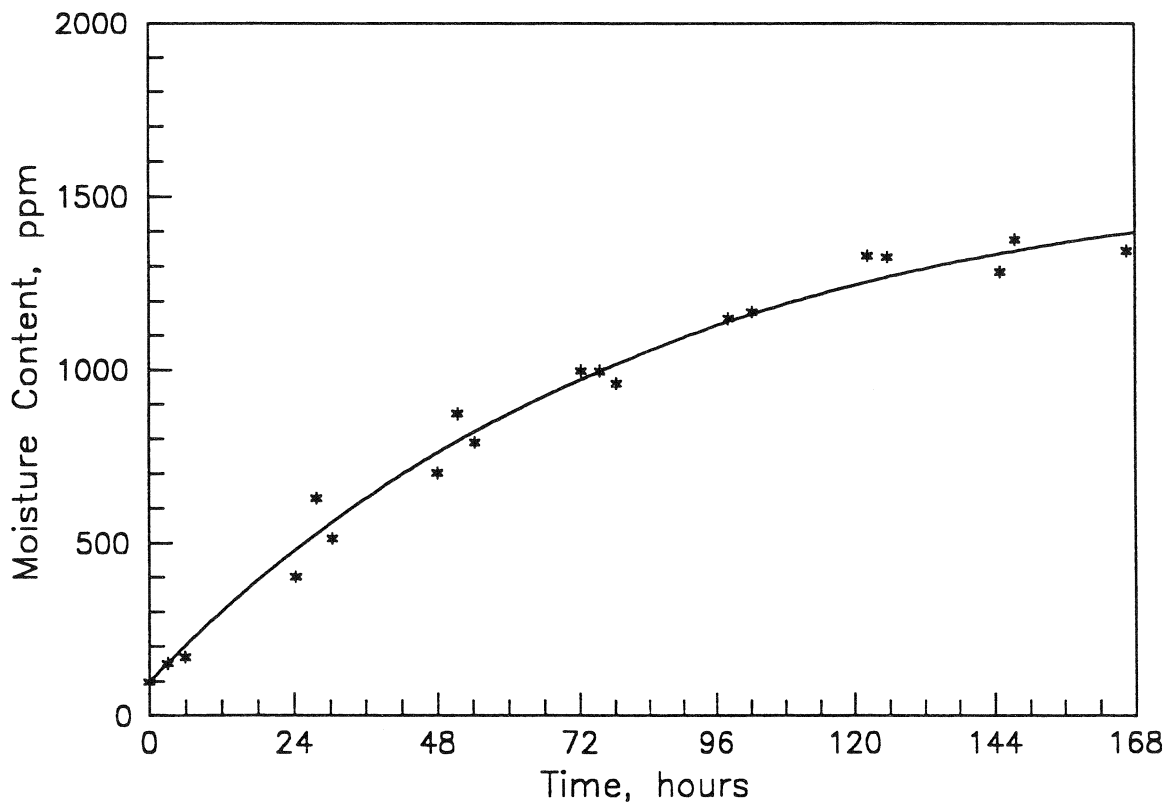
FIG H-9: MOISTURE PICKUP OF SAMPLE LS-010**FIG H-10: MOISTURE PICKUP OF SAMPLE LS-011**

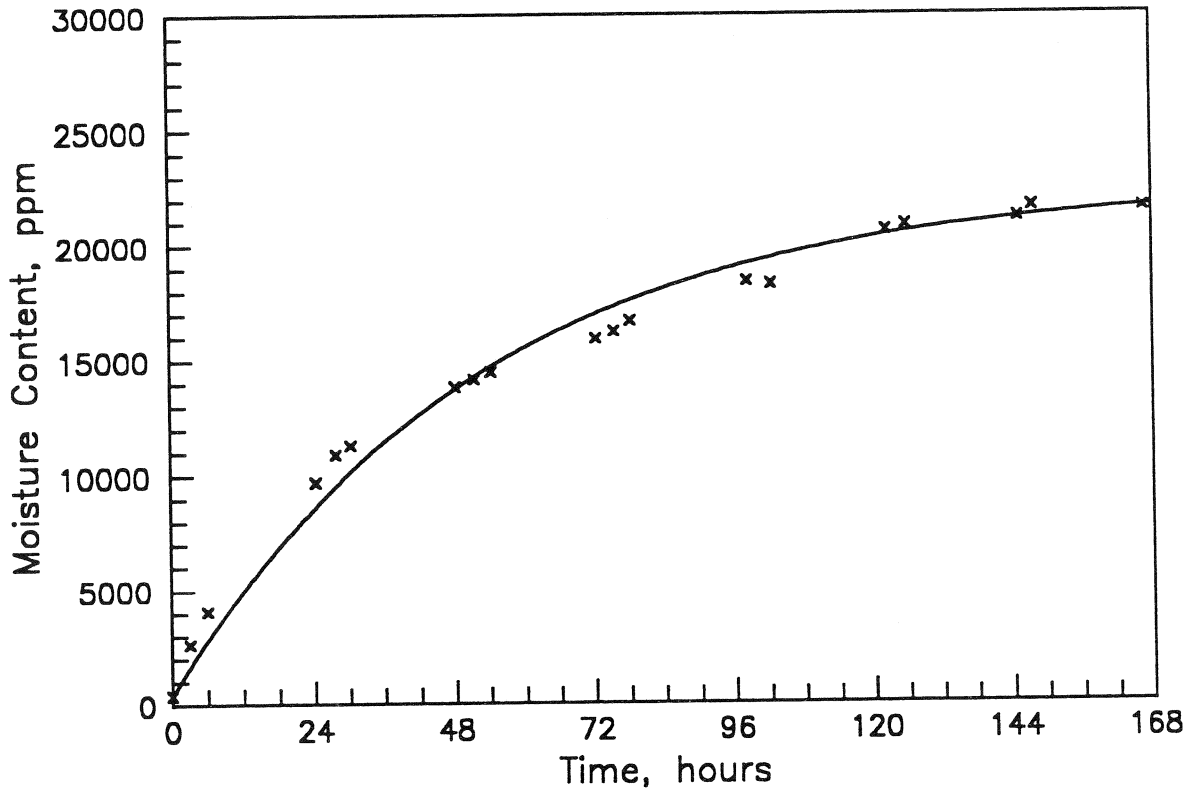
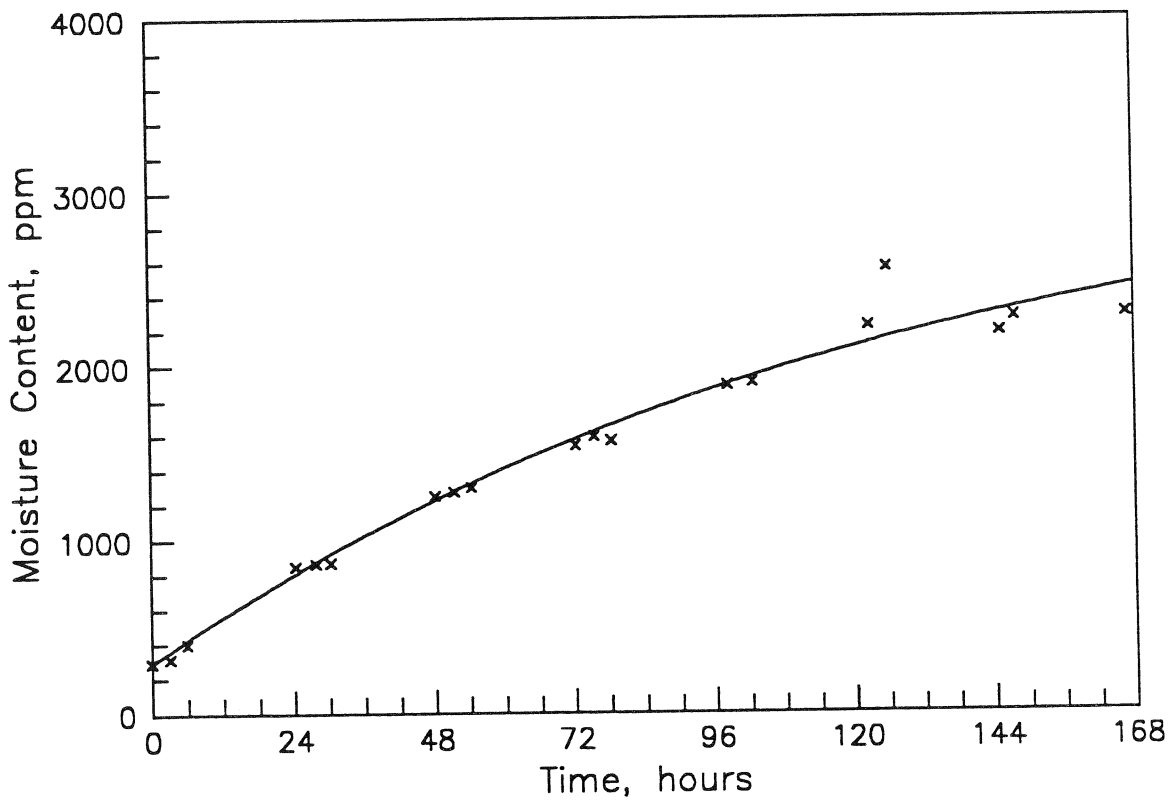
FIG H-11: MOISTURE PICKUP OF SAMPLE LS-012**FIG H-12: MOISTURE PICKUP OF SAMPLE LS-013**

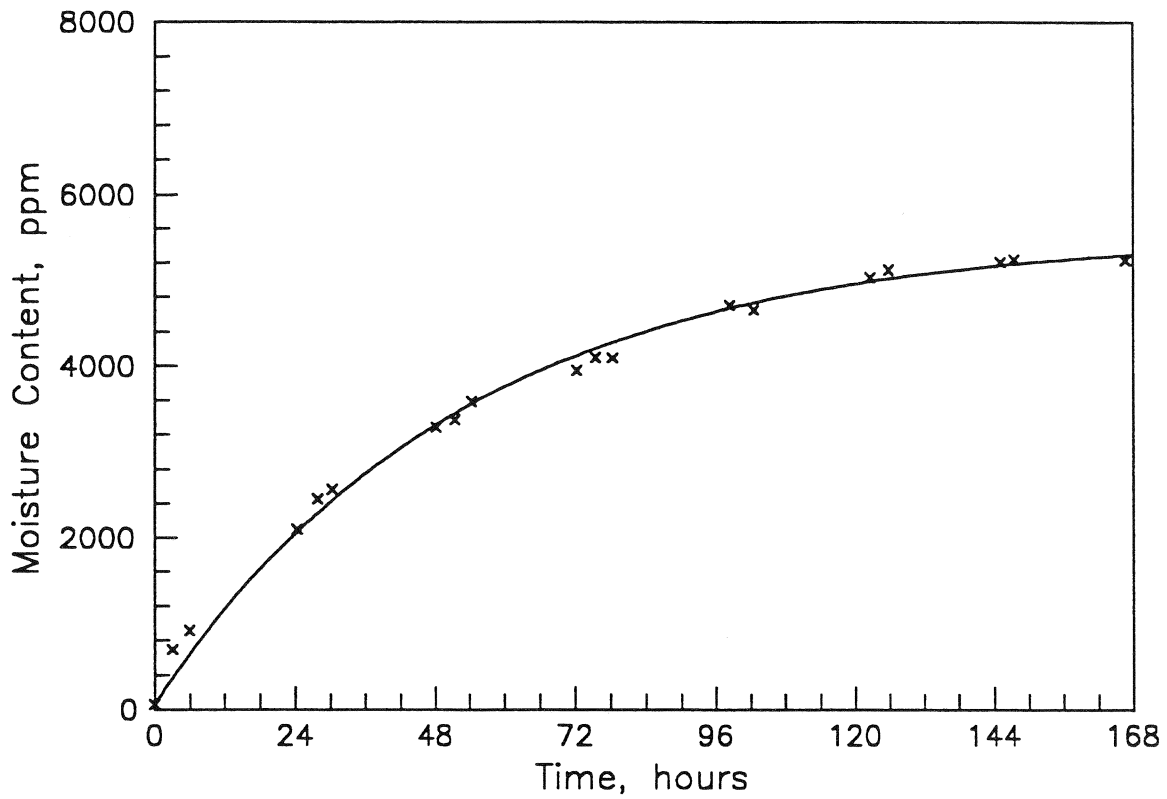
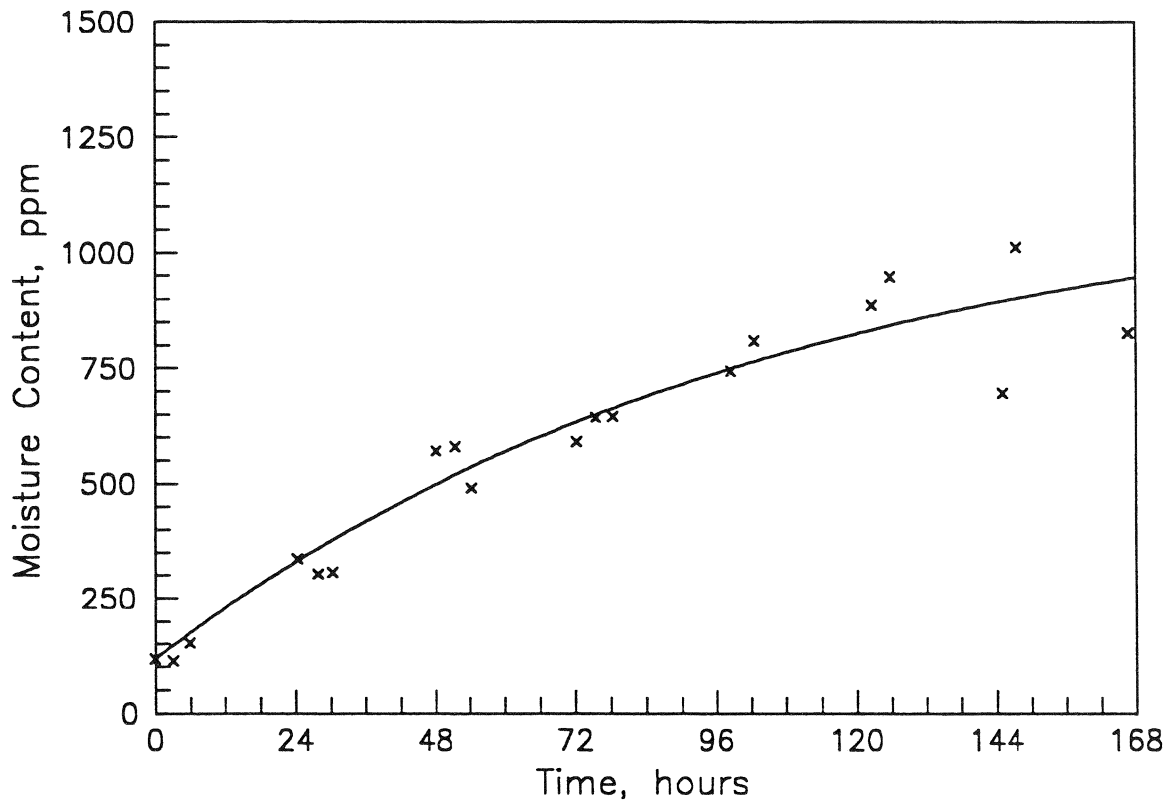
FIG H-13: MOISTURE PICKUP OF SAMPLE LS-014**FIG H-14: MOISTURE PICKUP OF SAMPLE LS-015**

FIG H-15: MOISTURE PICKUP OF SAMPLE LS-016

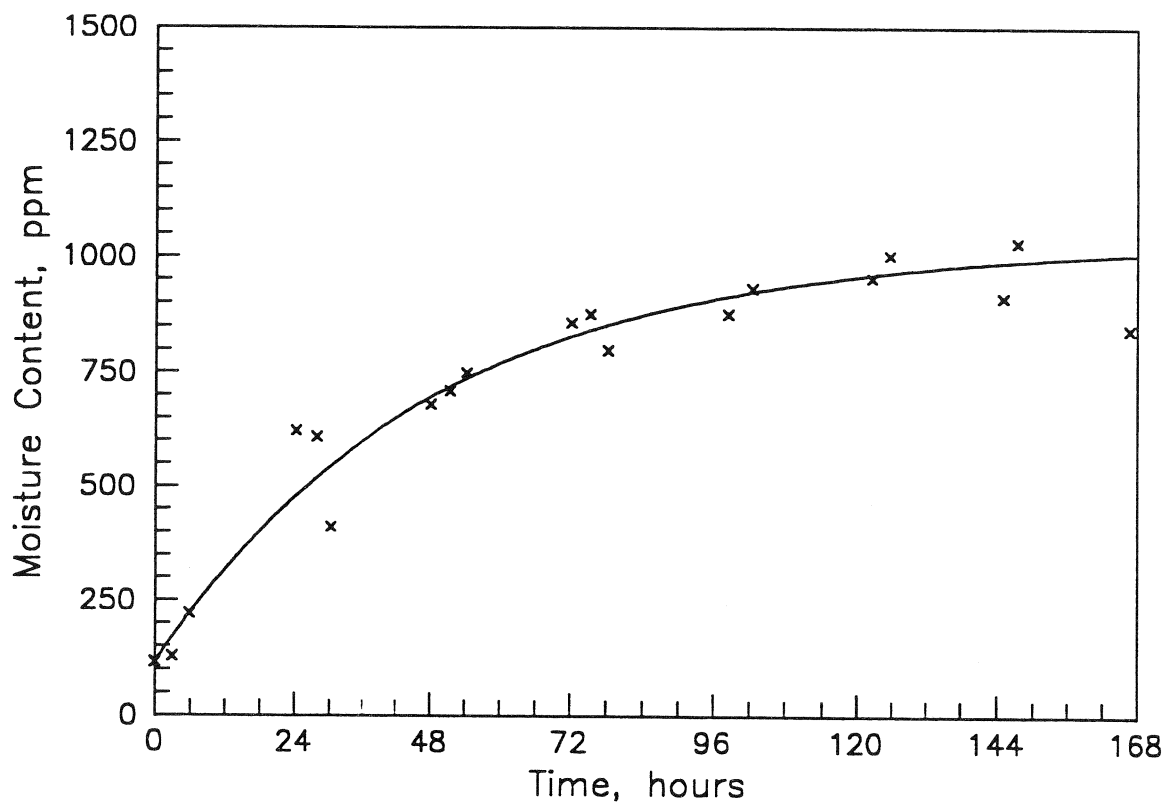


FIG H-16: MOISTURE PICKUP OF SAMPLE LS-017

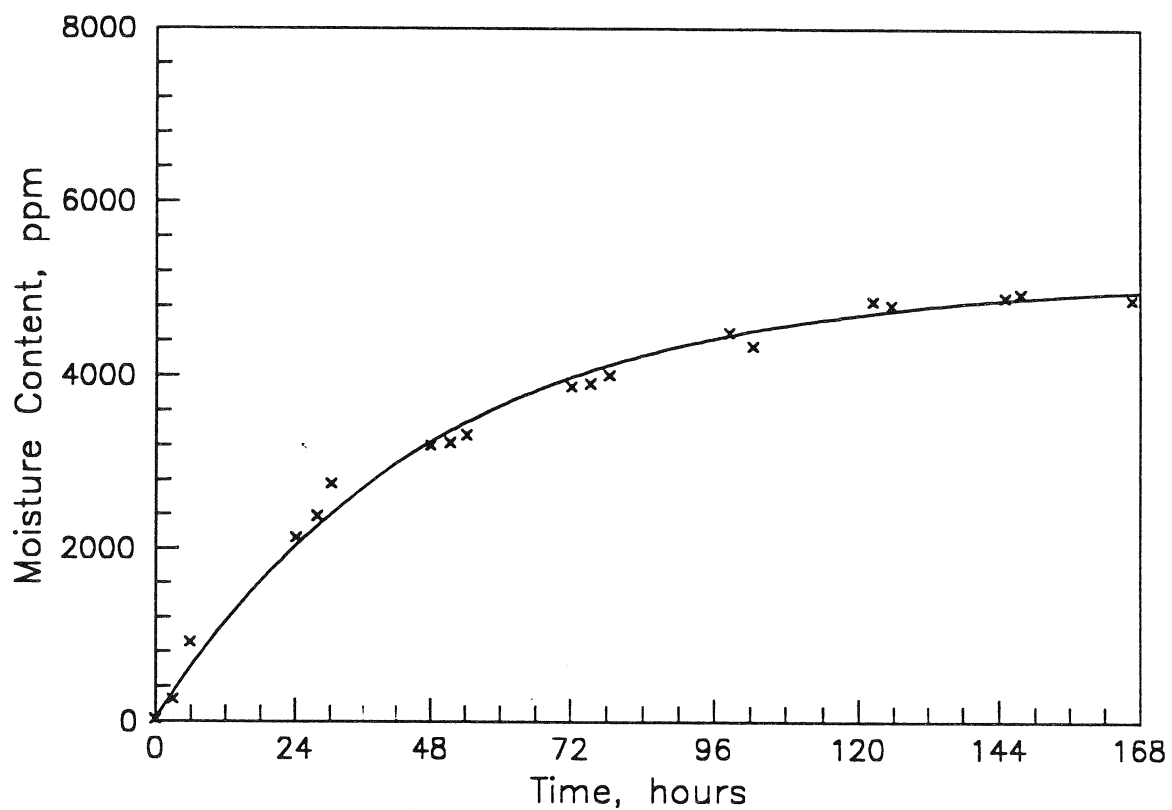
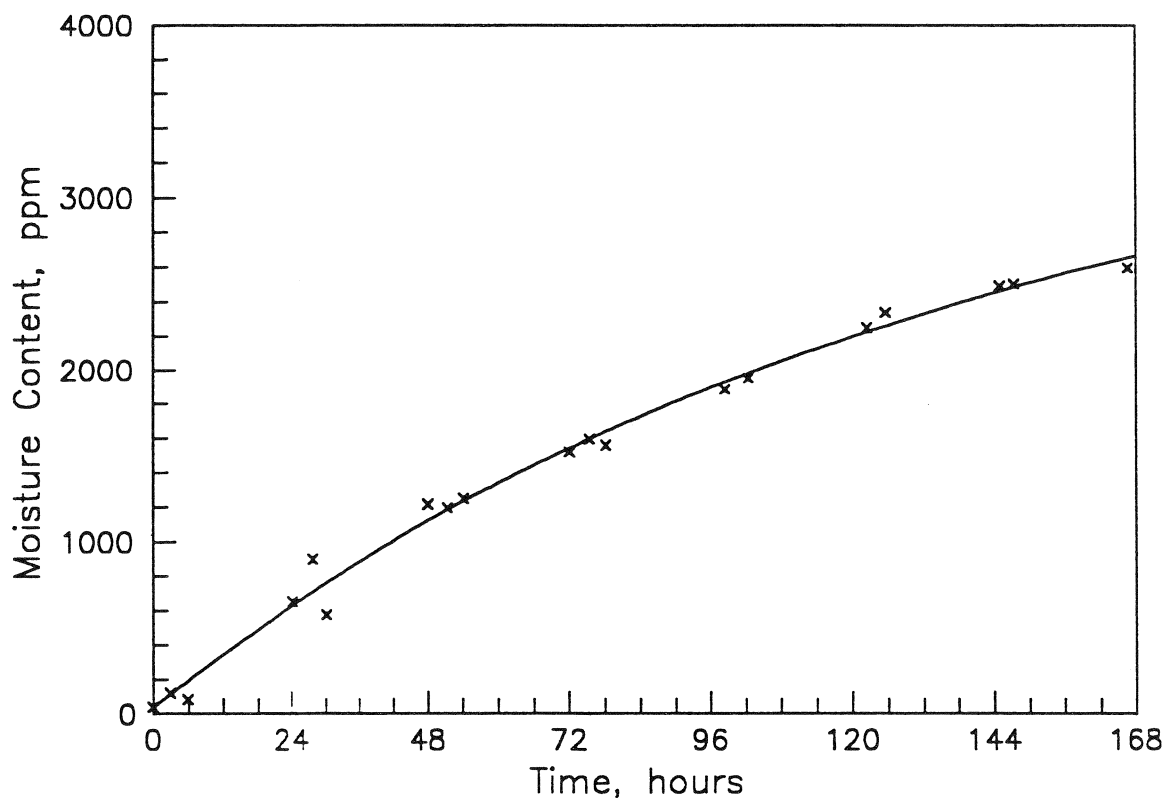
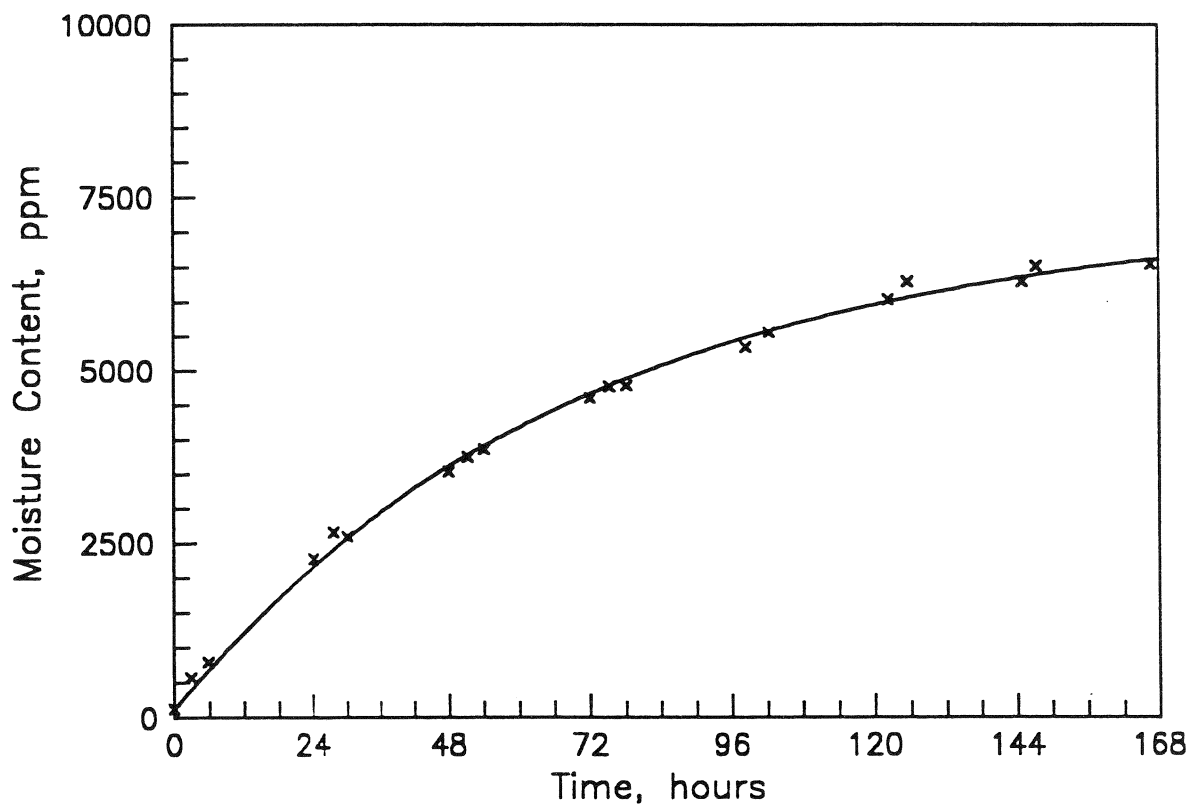


FIG H-17: MOISTURE PICKUP OF SAMPLE LS-019**FIG H-18: MOISTURE PICKUP OF SAMPLE LS-020**



3.0 MISCIBILITY

Sealed glass tubes were prepared containing 20% lubricant/80% R-134a, where 20% lubricant consists of 90% synthetic/10% mixed mineral oil. Mixed mineral oil is a 50/50% mixture of Idemitsu YN-9 and BVM-100N.

The tubes were sealed and allowed to warm to room temperature, where the phase conditions were noted. The samples were then cooled from room temperature to -40°C at a very slow rate; observations were made of the temperature at which a third phase appeared. A similar procedure was followed for the heating data, placing the tubes into an oven and gradually raising temperature while observing the contents for phase separation. The temperature at which this occurred is given in Table M-1.

<u>Lubricant Sample</u>	<u>Cooling Phase Separation Temp, C</u>	<u>Heating Phase Separation Temp, C</u>
LS-001	< -40	35
LS-003	+7	75
LS-004	-29	89
LS-005	three phases at all temperatures	three phases at all temperatures
LS-006	-18	66
LS-007	+14	67
LS-008	< -40	69
LS-009	-9	85
LS-010	-24	88
LS-011	< -40	> 93
LS-012	< -40	28
LS-013	< -40	73
LS-014	< -40	78
LS-015	-10	83
LS-016	-7	78
LS-017	< -40	77
LS-019	< -40	83
LS-020	< -40	54

TABLE M-1: MISCIBILITY OF LUBRICANT SAMPLES WITH HFC-134a

4.0 STABILITY

Sealed tubes were prepared according to ANSI/ASHRAE 97-1989 containing equal volumes (1 cc) of oil and HFC-134a, where the 1 cc of oil consisted of 90% synthetic/10% mixed mineral oil, and the HFC-134a was doped with 1% CFC-12. This series of tubes was prepared at two moisture levels, using the synthetic lubricants as received and samples at the moisture level given in Table H-1 after 168 hours exposure. Each tube also contained metal catalysts of a copper/aluminum/steel couple linked by aluminum wire, arranged so that the copper is not in direct contact with the steel.

Five replicate tubes were prepared for each sample at the two moisture levels, for a total of 180. These tubes were then aged in large aluminum blocks for 14 days at 175°C; after aging, visual inspection was performed for corrosion, film formation, extracts, wall deposits and copper transfer. Color change of the liquid phase was determined by comparison to ASTM D1500 standards. Two of the aged tubes were used for chloride and fluoride determination by specific ion electrode and two tubes were opened for measurement of total acid number according to ASTM D 664 to a final pH of 11.0 (acid number of the as received lubricants was also measured).

Tables S-1 and S-2 which follow give the results of these tests for the as received and the high moisture tubes respectively. Percent refrigerant reacted has been calculated by assuming that each halide atom present was the result of the destruction of one refrigerant molecule. The quantity of chloride found in the tubes after aging is reported in micrograms.

<u>Sample</u>	<u>Color Change</u> <u>From</u> <u>To</u>	<u>Chloride</u> <u>ion, μg</u>	<u>% R-134a</u> <u>Reacted</u>	<u>TAN Change</u> <u>From</u> <u>To</u>	<u>Visual Inspection</u>
LS-001	2.0 3.0	10 18	0.002 <0.001	1.30 1.4 1.30 1.4	Cu, Al and Fe clean and bright. Small amount of white, flaky extracts. No film, corrosion or copper transfer.
LS-003	3.0 4.5	86 637	<0.001 <0.001	0.24 5.8 0.24 4.8	Al and Fe clean and bright. Cu black. No film, deposits, extracts, corrosion or Cu transfer.
LS-004	2.0 2.0	154 461	<0.001 <0.001	0.51 1.5 0.51 2.2	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-005	2.5 3.0	349 208	<0.001 <0.001	0.12 1.5 0.12 1.8	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-006	2.5 3.0	185 370	0.006 0.002	0.09 1.9 0.09 1.7	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer
LS-007	2.0 3.0	136 248	<0.001 <0.001	0.15 2.5 0.15 2.2	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-008	3.5 4.5	10 10	0.028 0.025	0.28 1.4 0.28 1.3	Cu, Al clean and bright. Fe slightly tarnished. No deposits, extracts, film, corrosion or copper transfer.
LS-009	2.0 3.0	120 185	0.021 0.007	0.36 1.2 0.36 1.2	Cu black, Fe tarnished. Aluminum clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-010	3.0 3.0	25 15	<0.001 <0.001	0.17 1.1 0.17 1.1	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-011	2.0 3.0	38 49	0.023 0.019	0.08 1.8 0.08 1.6	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-012	2.0 3.5	1505 2308	0.120 0.190	<0.02 4.0 <0.02 2.9	Cu and Al clean and bright. Fe dull gray. No deposits, extracts, film, corrosion or copper transfer.

TABLE S-1: STABILITY DATA - AS RECEIVED LUBRICANTS
(continued on following page)

<u>Sample</u>	<u>Color Change</u> <u>From</u> <u>To</u>	<u>Chloride</u> <u>ion, μg</u>	<u>% R-134a</u> <u>Reacted</u>	<u>TAN Change</u> <u>From</u> <u>To</u>	<u>Visual Inspection</u>
LS-013	3.0 3.0	35 35	0.037 0.210	0.17 1.7 0.17 1.8	Cu and Al clean and bright. Fe black. No deposits, extracts, film, corrosion or Cu transfer.
LS-014	2.0 2.0	0 0	0.004 0.003	<0.02 0.6 <0.02 0.9	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-015	2.0 3.0	14 14	0.430 0.460	0.07 1.2 0.07 1.3	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-016	2.0 2.0	21 33	0.002 0.002	<0.02 1.0 <0.02 1.5	Cu, Al clean and bright. Fe slightly spotted. No deposits, extracts, film, corrosion or copper transfer.
LS-017	2.0 2.0	30 30	0.003 0.002	<0.02 0.6 <0.02 0.7	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or Cu transfer.
LS-019	2.5 4.5	477 593	0.150 0.180	<0.02 0.7 <0.02 0.7	Cu, Al and Fe dull. No bright. No deposits, extracts, film, corrosion or Cu transfer.
LS-020	3.0 3.0	14 12	0.002 0.001	0.70 1.6 0.70 1.8	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.

TABLE S-1: STABILITY DATA - AS RECEIVED LUBRICANTS
(concluded)

<u>Sample</u>	<u>Color Change From</u>	<u>To</u>	<u>Chloride ion, μg</u>	<u>% R-134a Reacted</u>	<u>TAN Change From</u>	<u>To</u>	<u>Visual Inspection</u>
LS-001	2.5	3.0	104 81	0.026 0.027	1.30 1.30	1.4 1.2	Cu and Al clean & bright Fe black and corroded Flaky white deposits in liquid.
LS-003	3.0	4.5	0 27	0.002 0.002	0.24 0.24	7.2 6.7	Cu black. Al clean and bright. Fe tarnished. No deposits, extracts, film, or corrosion.
LS-004	2.5	2.5	31 61	0.001 <0.001	0.51 0.51	5.1 4.9	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-005	3.0	3.0	88 88	0.038 0.049	0.12 0.12	3.4 2.3	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-006	2.5	2.5	88 81	0.004 0.003	0.09 0.09	5.0 5.3	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer
LS-007	2.5	2.5	61 61	<0.001 <0.001	0.15 0.15	4.2 4.0	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-008	3.5	5.0	386 695	0.100 0.190	0.28 0.28	6.6 5.9	Cu, Al clean and bright. Fe black on edges. No deposits, extracts, film, corrosion or copper transfer.
LS-009	2.5	3.0	164 264	0.013 0.009	0.36 0.36	3.4 3.6	Cu tarnished/black spots. Al and Fe tarnished. No deposits, extracts, film.
LS-010	3.0	3.0	16 15	<0.001 <0.001	0.17 0.17	2.2 1.9	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-011	2.5	2.5	25 98	0.003 0.008	0.08 0.08	5.9 5.1	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
LS-012	2.0	2.5	401 869	0.022 0.020	<0.02 <0.02	0.6 0.7	Cu and Al clean and bright. Fe dull gray. No deposits, extracts, film, corrosion or copper transfer.

TABLE S-1: STABILITY DATA - HIGH MOISTURE LUBRICANTS
(continued on following page)

<u>Sample</u>	<u>Color</u> <u>From</u>	<u>Change</u> <u>To</u>	<u>Chloride</u> <u>ion, μg</u>	<u>% R-134a</u> <u>Reacted</u>	<u>TAN Change</u> <u>From</u>	<u>To</u>	<u>Visual Inspection</u>
IS-013	3.0	3.0	401 869	0.350 0.380	0.17 0.17	4.7 5.0	Cu and Al clean and bright. Fe black. No deposits, extracts, film, corrosion or Cu transfer.
IS-014	2.5	2.5	6 8	0.004 0.002	<0.02 <0.02	0.9 0.9	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
IS-015	2.5	2.5	25 34	0.005 0.003	0.07 0.07	4.0 4.1	Cu, Al and Fe clean and bright. Small amount of white, flaky extract. No corrosion or Cu transfer.
IS-016	2.5	2.5	31 40	0.003 0.004	<0.02 <0.02	1.4 2.0	Cu, Al, and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.
IS-017	2.0	3.0	57 57	0.003 0.003	<0.02 <0.02	0.9 0.9	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or Cu transfer.
IS-019	3.0	3.0	18 48	0.045 0.071	<0.02 <0.02	3.7 5.1	Cu and Al clean & bright. Fe black. Liquid phase cloudy. Grey-white deposits on tube bottom. No corrosion or copper transfer.
IS-020	3.0	3.0	8 8	0.002 0.001	0.70 0.70	11.7 11.5	Cu, Al and Fe clean and bright. No deposits, extracts, film, corrosion or copper transfer.

TABLE S-1: STABILITY DATA - HIGH MOISTURE LUBRICANTS
(concluded)

5.0 DESICCANT COMPATIBILITY

Sealed tube tests were conducted to determine compatibility of 4A-XH-5, both virgin and preaged, and XH-7 desiccant materials. The tubes were prepared according to ANSI/ASHRAE 97-1989 and contained 1cc of lubricant sample, 1cc of HFC-134a and about 0.5 grams of desiccant material. Virgin materials were aged 30 days at 125°C; 4A-XH-5 was preaged in a stainless steel bomb for 7 days at 125°C in CFC-12/mixed mineral oil at 300 psia. The beads were then removed from the bomb and carefully inserted into the tubes, without cleaning. Baseline tubes were also prepared and aged for both materials in CFC-12/mixed mineral oil.

After aging, the tubes were visually inspected for signs of desiccant bead degradation and color change; the beads from the CFC-12 tubes were analyzed for chloride ion and the HFC-134a beads for fluoride ion as a measure of halide uptake of the desiccant material. These values, given as micrograms of halide per gram of desiccant material, are given in table D-1 below.

In all cases, there was no visible evidence of degradation of the desiccant beads. Color change is the only visible evidence of chemical reaction, and there were no deposits, extracts or film in any of the tubes.

Sample	4A-XH-5 (Virgin)			4A-XH-5 (preaged)				XH-7		
	Color		$\mu\text{g halide/}$ g desiccant	Color		$\mu\text{g Cl}^-$ g des	$\mu\text{g F}^-$ g des	Color		$\mu\text{g halide/}$ g desiccant
	From	To		From	To			From	To	
MMO/R-12 ¹	2.5	2.5	137 Cl ⁻	---	---	---	---	2.5	2.5	350 Cl ⁻
LS-001	2.5	2.5	0.3 F ⁻	2.5	3.5	130	2.0	2.0	2.0	1.7 F ⁻
LS-003	3.0	3.5	1.5	3.0	4.0	102	0.4	3.0	3.0	5.7
LS-004	2.0	2.5	3.5	2.0	3.0	221	0.6	2.0	2.0	1.8
LS-005	2.5	4.0	2.0	3.0	4.0	105	0.2	2.5	4.0	1.1
LS-006	2.5	2.5	0.2	2.5	3.0	202	0.2	2.5	2.5	0.5
LS-007	2.0	2.0	0.8	2.5	3.0	78	<0.1	2.0	2.0	0.7
LS-008	4.0	4.5	1.0	5.0	5.0	342	1.0	4.0	5.0	3.6
LS-009	2.0	2.0	4.1	2.5	3.0	313	<0.1	2.0	2.0	0.8
LS-010	3.0	3.5	2.7	3.5	4.5	280	6.1	3.0	4.5	1.2
LS-011	2.5	2.5	1.9	3.0	3.5	221	3.8	3.0	3.0	2.8
LS-012	2.0	4.0	1.6	2.5	3.5	93	0.7	2.0	3.5	0.6
LS-013	3.0	3.0	3.1	3.0	3.5	120	0.7	3.0	3.0	0.6
LS-014	2.0	3.0	4.1	3.0	3.5	111	0.3	2.0	2.0	0.4
LS-015	2.0	2.5	0.5	3.0	3.0	71	0.2	2.0	2.0	4.3
LS-016	2.0	2.0	9.4	2.5	3.0	120	0.1	2.0	2.0	0.8
LS-017	2.0	2.0	0.6	2.5	3.0	191	0.2	2.0	2.0	0.4
LS-019	3.0	3.0	9.8	3.0	3.5	238	<0.1	3.0	3.0	0.7
LS-020	3.0	3.5	13.4	3.5	4.0	71	<0.1	3.0	3.0	0.0

¹Mixed Mineral Oil

TABLE D-1: DESICCANT COMPATIBILITY RESULTS

6.0 LUBRICITY

Failure load tests and five hour wear tests were conducted using a standard Falex pin and vee-block machine on pure lubricant samples as well as 90/10 weight percent mixtures of synthetic with mixed mineral oil, where mixed mineral oil is a 50/50 percent mixture of Idemitsu YN-9 and BVM-100N. Steel vee-blocks, AISI 1137 and aluminum vee-blocks, die cast 390, were run against no. 8 steel pins, AISI 3135. HFC-134a was bubbled through the lubricants for 30 minutes prior to beginning the test to insure saturation, and the refrigerant was continuously bubbled through the lubricant for the duration of the test. Additionally, the same tests were performed for the mixed mineral oil saturated with CFC-12 for base-line information.

The failure load test consists of a two minute run-in period at 250 lbs. direct load, a two minute off period and then running at a constantly increasing load until failure occurs or 2,000 lbs load is reached, whichever comes first. Test specimens were steel vee-blocks and steel pins, and duplicate runs were made for each lubricant. The results of this series of tests are summarized in Table L-1 (giving the arithmetic average of the duplicate runs), and Figures LF-0 through LF-18 are graphs of the direct load, torque and oil temperature for each test run. A computer based data collection system was used to take a sample point at approximately three second intervals, and Figures LF-0 through LF-18 are plots of this data connected by straight line segments.

Wear tests consisted of a two minute run-in period, followed by running at a constant 250 lb. direct load for five hours. Tests were made with both aluminum vee-blocks against steel pins and steel vee-blocks against steel pins. Wear of the test specimens, as measured by the advancement of the loading device to maintain the constant load, was recorded at discrete time intervals; this data is plotted in Figures LW-1 through LW-36, and summarized in Tables L-2 and L-3. In these tables, the wear scar was measured microscopically at the end of the test and the load supported was calculated from knowledge of the direct load and the wear scar area. Total wear is the thickness of test specimen material which was lost during the test, and the weight of the test pins were measured before and after the test. Oil temperature is the temperature of the lubricant at the end of the test.

Viscosity of the 90/10 weight percent mixtures was measured at 40°C according to ASTM D 445. These measurements are reported in Table L-0, along with viscosity of the neat lubricants as given by the suppliers for comparison purposes. Review of this data will reveal that samples LS-001 and LS-019 show an increase in viscosity upon mixing, while all other samples show a decrease. Review of blend calculations (ASTM D 341) shows that the viscosity of the mixtures depends on the volume fraction and on the viscosity at 40 and 100°C of both (or all three in this case) components. This is further complicated by the fact that the viscosity indices of the samples are widely different. The change in the samples on mixing shows no apparent correlation to the viscosity at 40°C or to the viscosity index.

<u>Sample</u>	<u>Neat Lubricant</u>	<u>90/10 Mixture</u>
LS-001	100.0	107.0
LS-003	96.1	82.9
LS-004	92.6	81.8
LS-005	134.0	112.0
LS-006	124.0	101.9
LS-007	140.9	119.7
LS-008	102.4	97.6
LS-009	79.1	71.3
LS-010	97.0	84.6
LS-011	128.0	102.1
LS-012	140.6	135.7
LS-013	99.2	94.8
LS-014	76.5	71.2
LS-015	125.0	105.3
LS-016	146.6	138.3
LS-017	154.0	138.2
LS-019	95.0	96.1
LS-020	120.6	105.5

**TABLE L-0: KINEMATIC VISCOSITY, CST, AT 40C
OF NEAT SAMPLES AND 90/10 MIXTURES**

<u>Sample</u>	<u>Neat Lubricant</u>	<u>Faliure Load, psi</u> <u>90/10 Mixture</u>
MMO ¹ /CFC-12	900	----
LS-001 ²	> 2,000	> 2,000
LS-003	1,345	1,265
LS-004	> 2,000	> 2,000
LS-005	1,063	1,025
LS-006	1,313	1,338
LS-007	1,263	1,250
LS-008	1,138	1,175
LS-009	> 2,000	> 2,000
LS-010	1,063	1,063
LS-011	1,250	1,138
LS-012	975	900
LS-013	1,425	1,213
LS-014	1,038	875
LS-015	938	988
LS-016	788	850
LS-017	850	863
LS-019	1,075	963
LS-020	> 2,000	1,975

¹Mixed Mineral Oil

²All synthetics saturated with HFC-134a

TABLE L-1: SUMMARY OF FAILURE LOAD DATA

<u>Sample</u>	<u>Wear Scar, mm</u>	<u>Load, psi</u>	<u>Total Wear, mm</u>	<u>Pin weight Loss, g</u>	<u>Oil Temp, C</u>
MMO/CFC-12 ¹	0.648	14,000	0.086	0.043	86
LS-001 ²	0.195	46,400	0.004	0.010	72
LS-003	0.240	37,400	0.012	0.004	64
LS-004	0.297	30,500	0.003	0.008	94
LS-005	0.719	12,600	0.095	0.055	73
LS-006	0.195	46,400	< 0.002	0.001	90
LS-007	0.555	16,300	0.078	0.039	80
LS-008	0.586	15,500	0.072	0.020	69
LS-009	0.672	13,500	0.075	0.024	84
LS-010	0.602	15,100	0.130	0.071	80
LS-011	0.398	22,800	0.012	0.001	106
LS-012	0.609	14,500	0.097	0.046	82
LS-013	0.516	17,600	0.102	0.058	67
LS-014	0.398	22,800	0.035	0.017	71
LS-015	0.453	20,000	0.018	0.006	88
LS-016	0.938	9,700	0.127	0.040	77
LS-017	0.320	28,300	0.021	0.006	74
LS-019	0.914	9,900	0.749	0.505	86
LS-020	0.367	24,700	0.011	0.011	95

¹Mixed Mineral Oil

²All synthetics saturated with HFC-134a

TABLE L-2: NEAT LUBRICANT WEAR TEST RESULTS
STEEL VEE-BLOCKS, STEEL PINS, 250 LB. DIRECT LOAD

<u>Sample</u>	<u>Wear Scar, mm</u>	<u>Load, psi</u>	<u>Total Wear, mm</u>	<u>Pin weight Loss, g</u>	<u>Oil Temp, C</u>
MMO/CFC-12 ¹	0.648	14,000	0.086	0.043	86
LS-001 ²	0.226	40,000	0.009	0.011	76
LS-003	0.211	43,000	0.007	0.013	95
LS-004	0.156	58,000	0.005	0.008	91
LS-005	0.820	11,000	0.095	0.035	81
LS-006	0.195	46,500	0.004	0.005	99
LS-007	0.602	15,000	0.099	0.051	86
LS-008	0.375	24,000	0.067	0.043	69
LS-009	0.719	12,600	0.048	0.018	83
LS-010	0.531	17,100	0.095	0.045	87
LS-011	0.305	29,800	0.014	0.002	102
LS-012	0.609	14,900	0.074	0.047	88
LS-013	0.586	15,500	0.083	0.035	64
LS-014	0.313	29,000	0.014	0.008	70
LS-015	0.453	20,000	0.034	0.032	92
LS-016	0.945	9,600	0.122	0.035	72
LS-017	0.289	31,400	0.018	0.013	65
LS-019	0.781	11,600	0.196	0.110	74
LS-020	0.359	25,200	0.005	0.016	101

¹Mixed Mineral Oil

²All synthetics saturated with HFC-134a

TABLE L-3: 90/10 MIXTURE WEAR TEST RESULTS
STEEL VEE-BLOCKS, STEEL PINS, 250 LB. DIRECT LOAD

<u>Sample</u>	<u>Wear Scar, mm</u>	<u>Load, psi</u>	<u>Total Wear, mm</u>	<u>Pin weight Loss, g</u>	<u>Oil Temp,</u>
MMO/CFC-12 ¹	0.941	9,600	0.066	0.022	97
LS-001 ²	0.460	19,700	0.014	0.008	71
LS-003	0.516	17,600	0.025	0.021	98
LS-004	0.703	12,900	0.067	0.023	81
LS-005	1.094	8,300	0.227	0.109	77
LS-006	0.586	15,500	0.016	0.006	103
LS-007	0.914	9,900	0.123	0.069	87
LS-008	0.828	10,900	0.069	0.026	66
LS-009	0.641	14,100	0.032	0.017	80
LS-010	1.234	7,300	0.354	0.170	84
LS-011	0.570	15,900	0.005	0.008	111
LS-012	0.914	9,900	0.256	0.146	70
LS-013	0.766	11,800	0.053	0.015	65
LS-014	0.594	15,300	0.021	0.004	90
LS-015	0.695	13,000	0.065	0.029	88
LS-016	1.063	8,500	0.183	0.094	83
LS-017	0.523	17,300	0.012	0.001	103
LS-019	1.727	5,300	0.363	0.079	80
LS-020	0.430	15,500	0.002	0.002	83

¹Mixed Mineral Oil

²All synthetics saturated with HFC-134a

TABLE L-4: NEAT LUBRICANT WEAR TEST RESULTS
ALUMINUM VEE-BLOCKS, STEEL PINS, 250 LB. DIRECT LOAD

<u>Sample</u>	<u>Wear Scar, mm</u>	<u>Load, psi</u>	<u>Total Wear, mm</u>	<u>Pin weight Loss, g</u>	<u>Oil Temp, C</u>
MMO/CFC-12 ¹	0.941	9,600	0.066	0.022	97
LS-001 ²	0.477	19,000	0.026	0.003	58
LS-003	0.555	16,300	0.030	0.023	90
LS-004	0.648	14,000	0.039	0.012	79
LS-005	1.117	8,100	0.257	0.017	71
LS-006	0.563	16,000	0.007	0.006	100
LS-007	1.086	8,300	0.256	0.108	84
LS-008	0.797	11,400	0.078	0.046	70
LS-009	0.938	9,700	0.116	0.066	82
LS-010	0.953	9,500	0.192	0.093	76
LS-011	0.523	17,300	0.002	0.007	112
LS-012	0.914	9,900	0.227	0.115	71
LS-013	0.727	12,500	0.060	0.027	74
LS-014	0.797	11,400	0.095	0.037	80
LS-015	0.578	15,700	0.039	0.016	88
LS-016	1.063	8,500	0.275	0.112	84
LS-017	1.023	12,300	0.051	0.013	83
LS-019	1.938	4,700	1.005	0.486	109
LS-020	0.586	15,500	0.016	0.015	109

¹Mixed Mineral Oil

²All synthetics saturated with HFC-134a

TABLE L-5: 90/10 MIXTURE WEAR TEST RESULTS
ALUMINUM VEE-BLOCKS, STEEL PINS, 250 LB. DIRECT LOAD

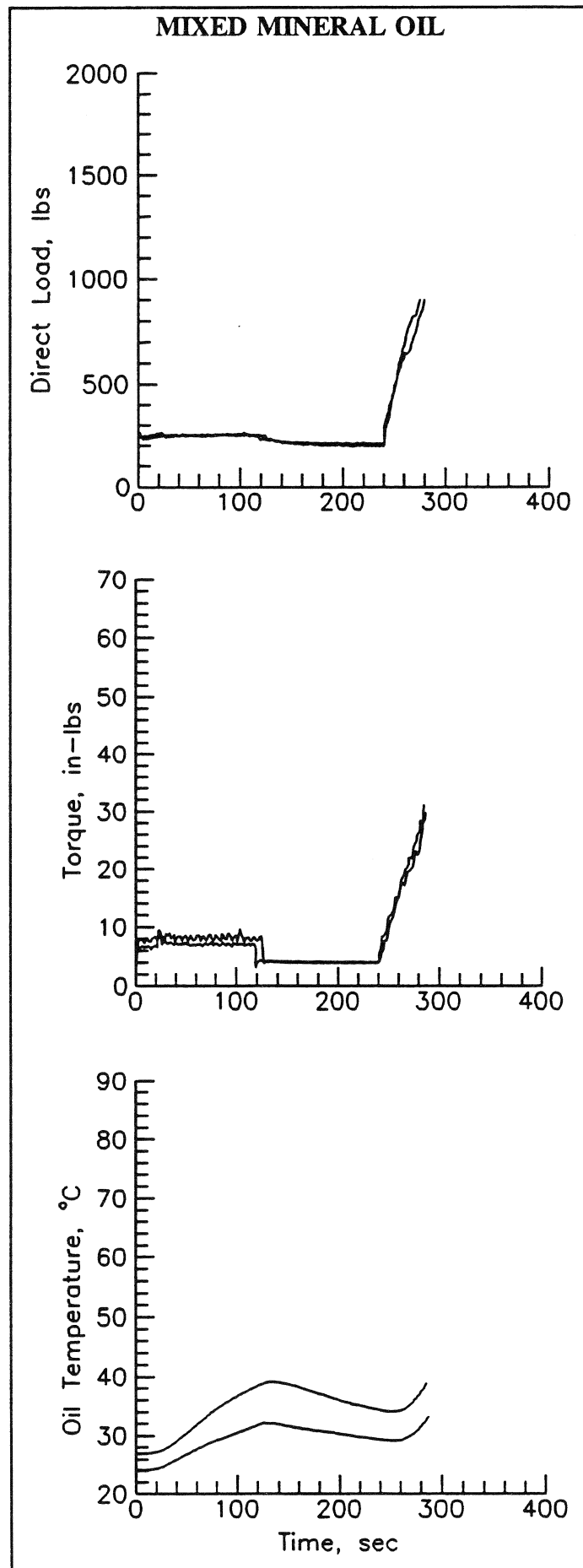
FIGURE LF-0: MIXED MINERAL OIL FAILURE LOAD TEST_(R-12 SATURATED)

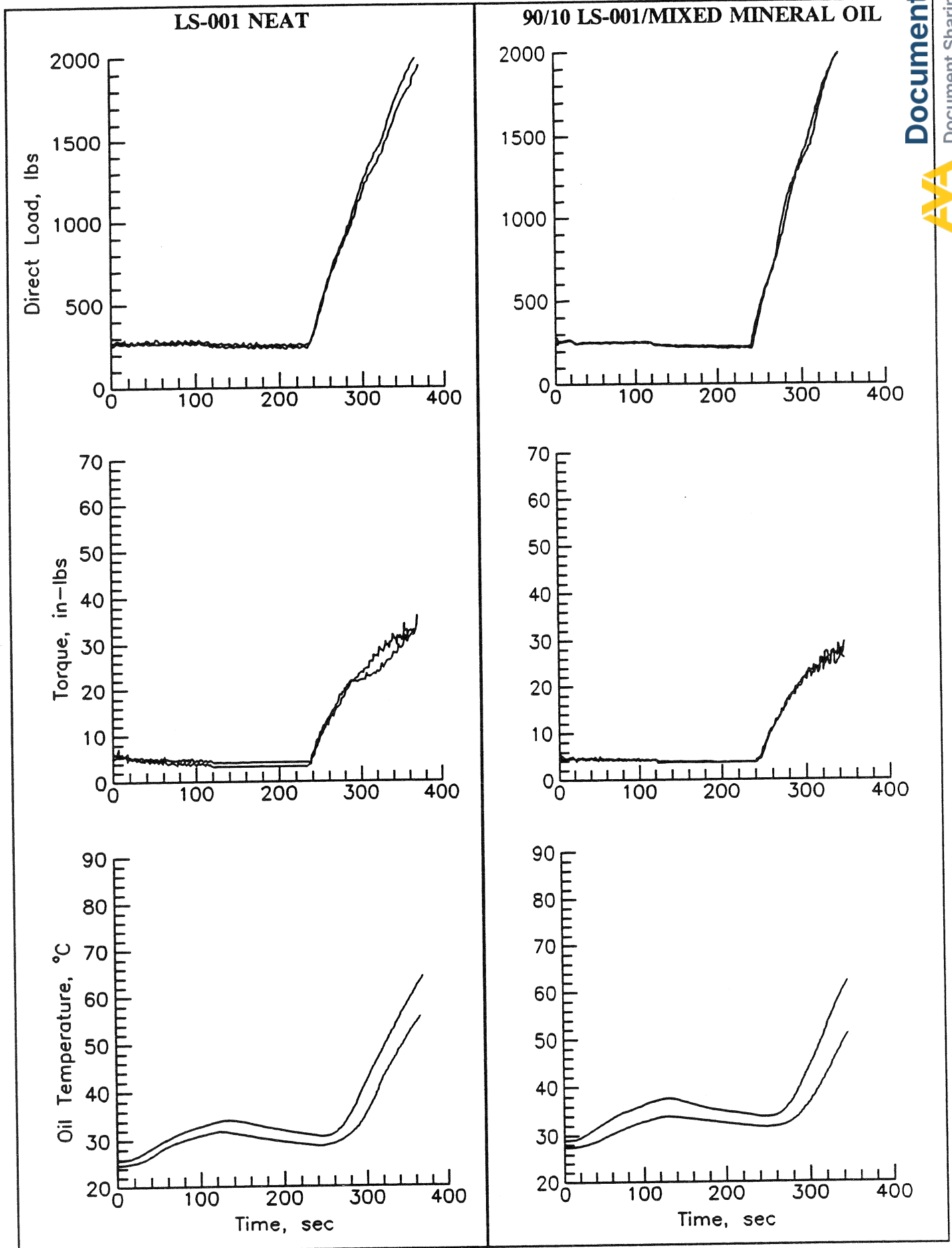
FIGURE LF-1: LUBRICANT SAMPLE LS-001 FALEX FAILURE LOAD TEST (R-134a SATURATED)

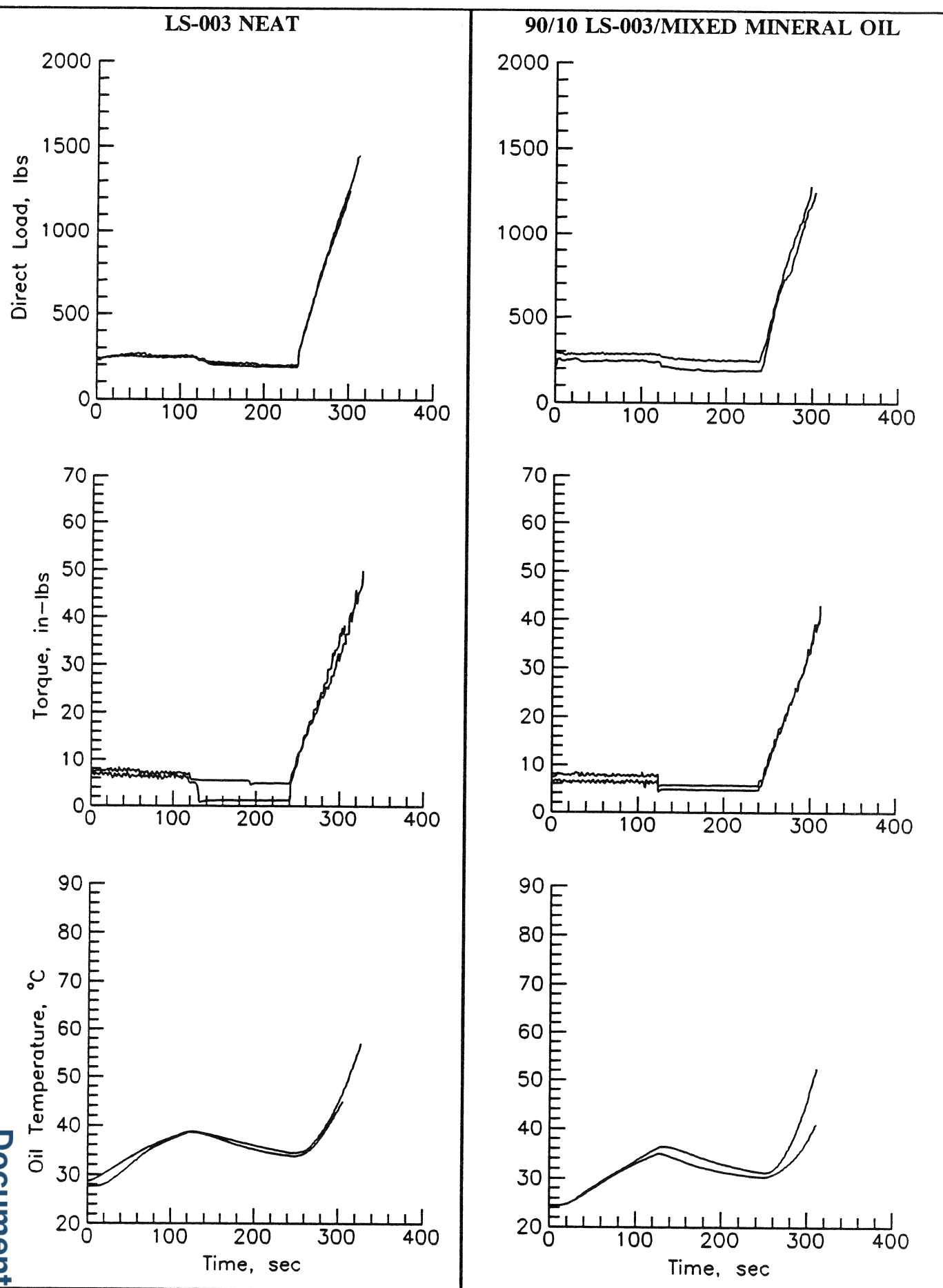
FIGURE LF-2: LUBRICANT SAMPLE LS-003 FALEX FAILURE LOAD TEST (R-134a SATURATED)

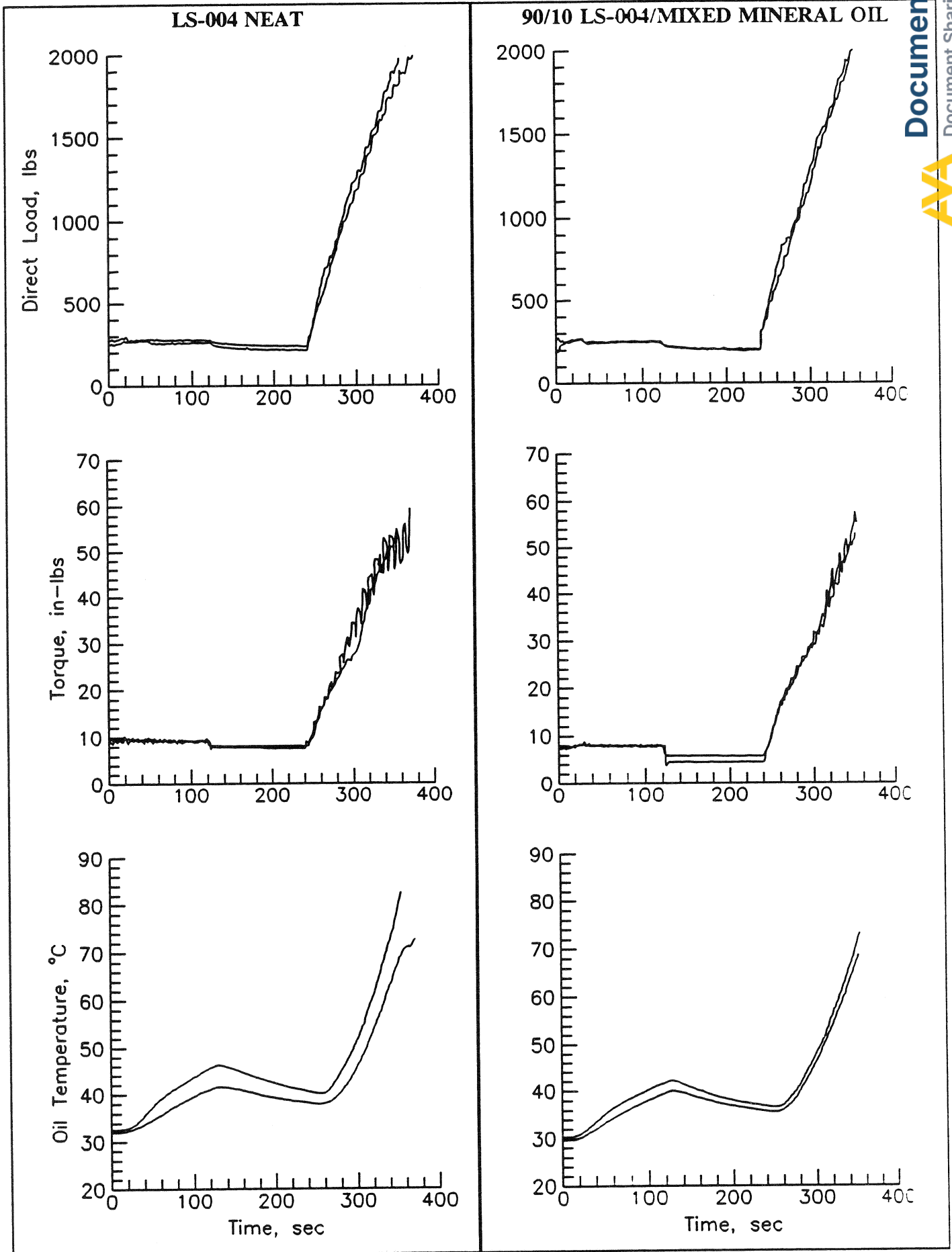
FIGURE LF-3: LUBRICANT SAMPLE LS-004 FALEX FAILURE LOAD TEST (R-134a SATURATED)

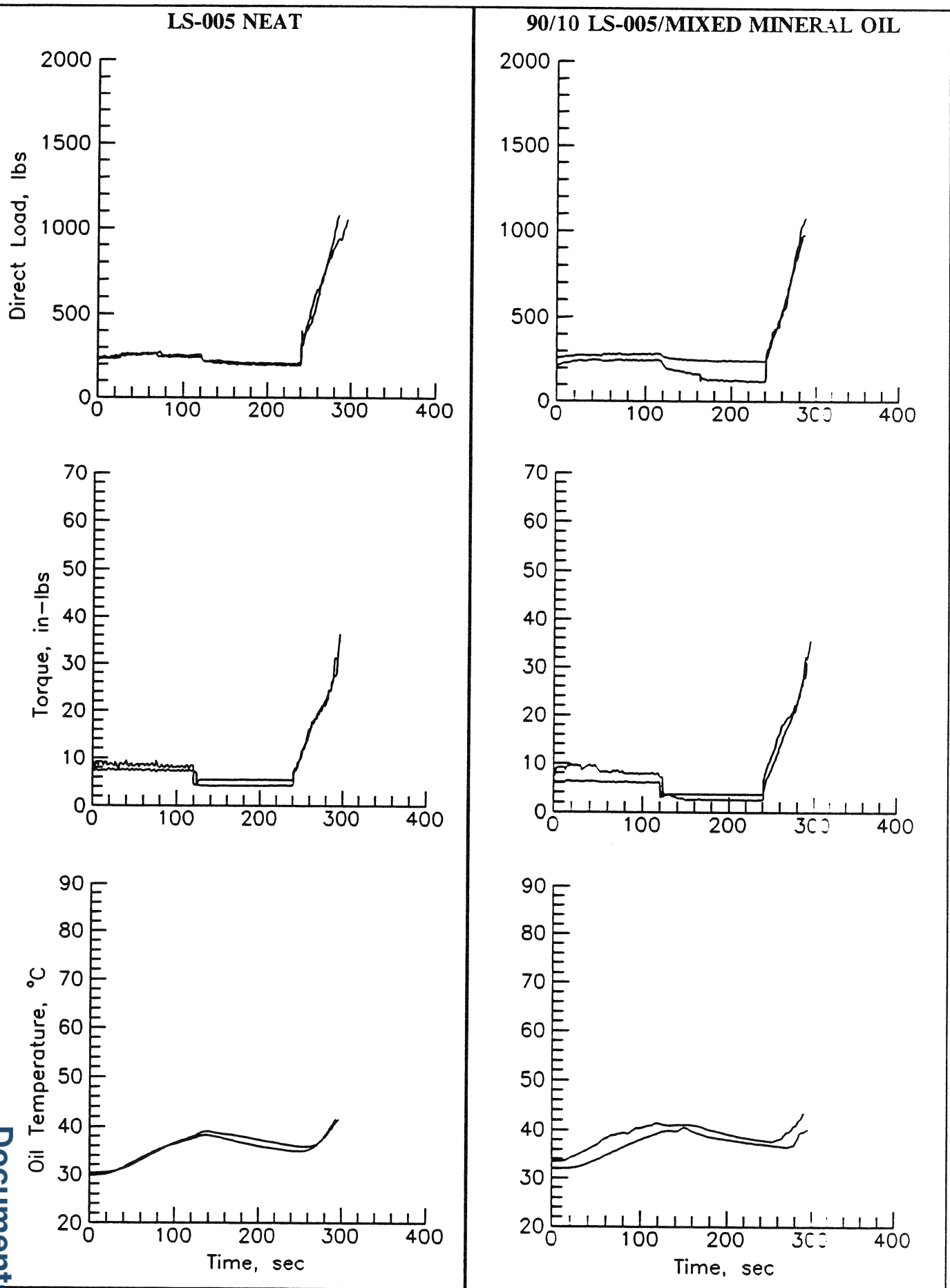
FIGURE LF-4: LUBRICANT SAMPLE LS-005 FALEX FAILURE LOAD TEST (R-134a SATURATED)

FIGURE LF-5: LUBRICANT SAMPLE LS-006 FALEX FAILURE LOAD TEST (R-134a SATURATED)

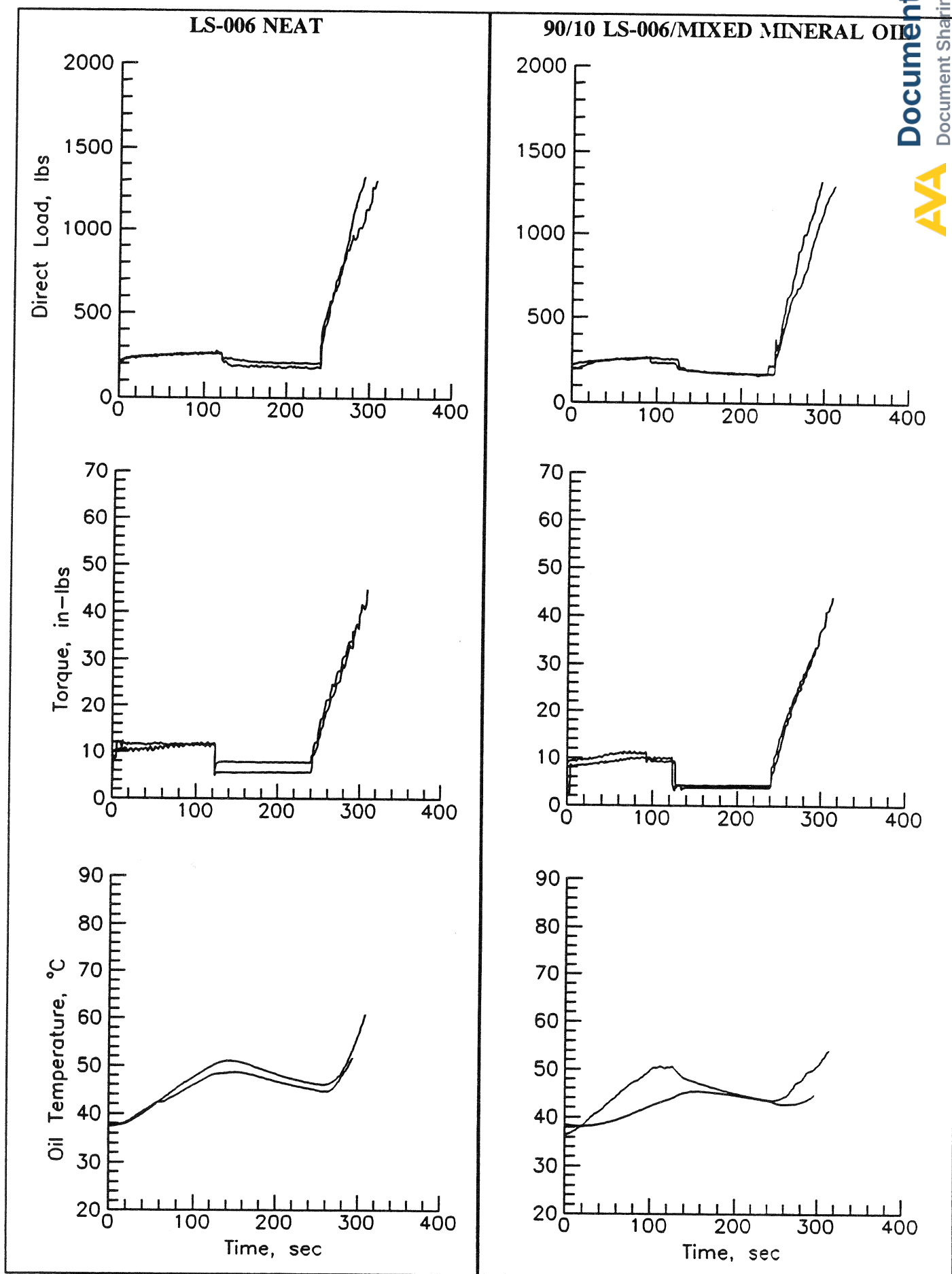


FIGURE LF-6: LUBRICANT SAMPLE LS-007 FALEX FAILURE LOAD TEST (R-134a SATURATED)