DEVELOPMENTAL SYNTHETIC FLUIDS



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TOWOLDMON0030980

HIGH TEMPERATURE LUBRICANTS

MONSANTO'S

Thermally and Oxidatively Stable Lubricants Designed for Use in High Performance Jet Engines

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PREFACE

As the World's foremost supplier of fire-resistant aircraft hydraulic fluids, Monsanto has established a reputation of foresightedness and dependability within the aviation industry. This pioneering spirit has provided the impetus for an ever-growing research program to develop new synthetic fluids to meet the many stringent needs and applications of the Air Transport and Aerospace Industries. It was with this eye to the future that Monsanto played a dominant role in the discovery and development of the polyphenyl ethers. The potentialities of these remarkable fluids led to an expansion of the over-all research effort to accommodate a separate and distinct program directed toward the discovery and development of jet engine lubricants having performance characteristics superior to those already in existence. It is the intent of this document to describe the results of that endeavor in terms of the products which emerged from it.

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INTRODUCTION

Monsanto's entre' into the jet engine lubricants field was a direct result of several programs which had as their objective the development of new high temperature fluid candidates by translation of basic scientific premises into specific chemical compositions. Subsequent investigations with the polyphenyl ethers produced a wide variety of these materials representing a spectrum of molecular weights and physical properties. All were characterized by the same extraordinary stability against degradation by heat and oxidation.

The polyphenyl ether which appears most suitable for use as a high temperature jet engine lubricant is the mixed-five ring composition which has a 40°F pour point (minimum flow point). However, the operational difficulties which could be encountered using such a lubricant are obvious. With this deficiency in mind, a concerted effort was undertaken to develop fluids which would simultaneously retain the good features of the polyphenyl ethers and overcome the deficient feature. With certain compromises, these objectives have been realized and a family of lubricants have emerged which represent a variety of operational or usable ranges. Certain members of this new family of lubricants have been selected to illustrate the general utility of the class.

It should be emphasized, however, that in describing specific and discrete fluids, it is not inferred that these are the only fluids which can be devised. On the contrary, an almost infinite number of fluids can now be derived with Monsanto's technological competence in this area. In addition, it is best to point out that some of the fluids to be described in this document are experimental or prototype fluids. Therefore, they may well be in the evolutionary improvement stage and are subject to change. However, no difficulty is foreseen in "tailor-making" a fluid to a specific application within the physical limits of the chemistry with which we are dealing.

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APPLICATION NEEDS

Before establishing definite targets, a careful study was made of existing lubricants and how they were satisfying existing needs. The ability of these lubricants to satisfy future applications were predicted to provide a complete forecast of unsatisfied needs in this area.

Dicarboxylic acid esters of the MIL-L-7808 (Type 1) lubricants, which have served the military and commercial aviation, cover a usable range of -75°F(-60°C) to 300°F(150°C). These oils, generally composed of formulated sebacate, azelate, and adipate esters, are not adequate for the newer commercial engines. To meet the needs of the higher performance engines, improved esters were developed based on polyalcohols of the pentaerythritol or trimethylolpropane types. Formulated with appropriate inhibitors, the current Type 1-1/2 - Type 2 lubricants (as they are frequently called) have a usable range of from -40°F(-40°C) to 400°F(200°C). A specification of the U. S. Navy -- MIL-L-23699 -- is applicable to most of these lubricants.

Beyond these now existing lubricants, only the polyphenyl ethers were available to satisfy the ever-increasing needs of the emerging higher-performance advanced engines. These remarkable fluids are expected to perform at ambient temperatures up to 700°F(370°C) in the normal air atmosphere found in the engine. The start-up capability (which we arbitrarily define as the temperature at which the oil's viscosity is 13,000 cs) is limited, however, in the case of an engine using a five-ring polyphenyl ether to temperatures in excess of 50°F(10°C). Thus, the engine designer was faced with the choice of limiting the engine oil ambients to 400°F(200°C) to accommodate an ester lubricant or adoption of some method or device to accommodate the high pour point of the polyphenyl ether.

Obviously, a need existed for a new lubricant having the low temperature properties of the esters and the high temperature stability of the polyphenyl ethers. While the need was obvious, the solution was not. In fact, a solution was considered to be virtually impossible. Since the Utopian solution was not available, the designers were then asked what would represent a realistic but significant advance in the state-of-the-art. The answer was a 0°F(-20°C) to 550°F(300°C) lubricant. This was possible!

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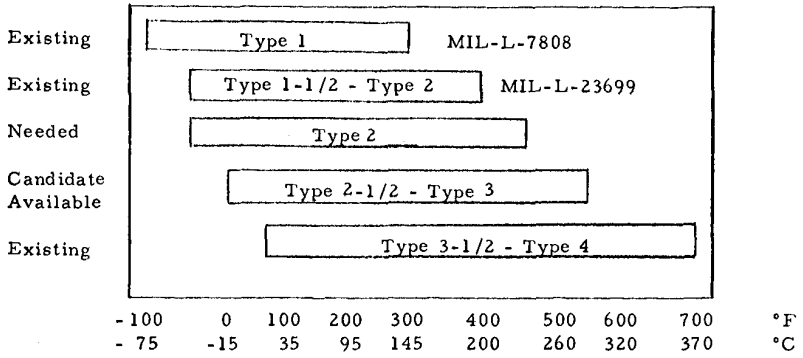
The chart below demonstrates visually the place occupied by the Type 2-1/2 - Type 3 lubricant in the over-all pattern. While a concession is made in the low-temperature start up, the over-all fluid range (length of the bar) is increased over both the Type 1 or Type 1-1/2 lubricants.

Lubricant Range



An extensive research program was initiated to seek candidate fluids which could provide the optimum balance of stability, viscosity, and volatility. The latter two properties are interdependent for any given class of compound, but will vary among a number of chemical classes. Using a specific level of volatility in the standard ASTM test method as a primary criteria, the ability of various fluids to meet the viscosity requisites was determined. The thermal and oxidative stability of those fluids meeting the viscosity-volatility requirements further narrowed the candidates. Performance-type gear and bearing tests ultimately eliminated all but one chemical class as a source of candidate fluids for this 0°F(-20°C) to 550°F(300°C) application. As a result of this program, candidate lubricants to fill the following general application needs have been developed.

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CANDIDATE LUBRICANTS

A. Type 2-1/2 Lubricant (MCS 293)

A fluid candidate was then selected for the 0° to 550°F range, which we choose to call the Type 2-1/2 application. The selection was based on what was believed to be an optimization of viscosity-volatility-performance characteristics of this class of fluids. This lubricant candidate, designated MCS 293, is described in detail in a succeeding section of this report. It should be emphasized that this lubricant is essentially an unformulated base stock which does not contain inhibitors or additives to improve wear or boundary lubrication.

B. Inhibited Type 2-1/2 Lubricant (MCS 316)

MCS 293 has been found corrosive to pure copper metal under certain conditions. Although copper as such will probably not be used in the advanced high performance engines, this deficiency of the fluid is regarded by some as being significant. Consequently, an inhibited version is being developed which virtually eliminated the fluid's attack on copper and imposes a minimum depreciation of the cleanliness and over-all performance characteristics of the base lubricant. The specific properties and performance of the candidate, MCS 316, are described in a subsequent section of this brochure.

C. Low Viscosity Version (MCS 314 and MCS 315)

In discussions with various groups of engineers, the question of how volatile an oil can be to function properly in an engine arose on several occasions. The frequency with which this question came up prompted the development of a higher volatility version which could have the advantage of better low temperature viscosity. Several candidates (MCS 314 and MCS 315) are described in detail and are available for evaluation. The fluids described are in a very early stage of development and, consequently, are particularly susceptible to change or alteration. Indeed, further reductions in viscosity are obtainable in this area, but only if fairly drastic compromises are made on volatility.

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D. Low Altitude Stable Lubricant (MCS 232)

In response to an indicated need for better lubricants for ground-based or industrial gas turbines, a low-cost polyphenyl ether-type material was developed. It is not considered practical as an airborne lubricant because it combines high viscosity with high volatility. Its principal attributes are thermal and oxidative stability up to 700°F(370°C) and potential pricing at approximately 25 per cent that of the conventional polyphenyl ethers. As such, this lubricant could be ideally suited for stringent environment applications at normal sea level pressures, such as the industrial and marine gas turbine applications. In current operating equipment, the stability of this fluid would make it indestructible and virtually a lifetime lubricant. The candidate fluid for this application is described in detail in the section labeled MCS 232.

E. Type 3-1/2 Lubricants

OS-124, Monsanto's mixed isomeric five-ring polyphenyl ether, was the original Type 3-1/2 lubricant and has already undergone considerable application testing. It has found acceptance in a number of diversified applications, all of which have provided additional and independent confirmation of its extraordinary stability to heat, oxygen and radiation. Extensive studies have shown the fluid to be responsive to additives to further extend its performance capabilities.

Although not as extensively tested, sufficient eva uation of MCS 210 (Monsanto's four-ring polyphenyl ether) and OS-138 (Monsanto's six-ring polyphenyl ether) has been accomplished to confirm their near performance equivalency with OS-124. In applications where greater or lesser viscosity-volatility ranges are desired than that of OS-124, these other products may well be considered more suitable.

The selection of each of the candidate fluids has been based on our best estimate of the need. These fluids were designed with definite applications in mind and may not be the most suitable selection for other applications. Even in closely related applications, a different emphasis may be required which would alter the recommendation as to the precise fluid to be used. Consequently, it would be highly desirable to discuss specific problem applications before making any recommendations.

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LUBRICANT APPLICATIONS

TYPE 2-1/2 - TYPE 3

MCS 293 - Parent Lubricant

MCS 316 - Inhibited Version

MCS 314 & MCS 315 - Low Viscosity Versions

TYPE 3-1/2 - TYPE 4

OS-124 - Mixed Five-Ring Polyphenyl Ether

OS-138 - Six-Ring Polyphenyl Ether

MCS 210 - Mixed Four-Ring Polyphenyl Ether

INDUSTRIAL AND MARINE LUBRICANT

MCS 232 - Low Altitude Turbine Lubricant

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MCS 293

GAS TURBINE LUBRICANT

DEVELOPMENTAL SYNTHETIC FLUIDS

Preliminary Technical Data Sheet — September 1, 1964

MCS 293 is a pale yellow fluid which belongs to a chemical class related to the polyphenyl ethers. As such, it is characterized by outstanding thermal, oxidative, and radiation stability. Based upon experimental data, MCS 293 is capable of sustained operation in the presence of air at temperatures of 500-550°F (260-300°C) even though it is essentially an unformulated fluid and does not contain oxidation or corrosion inhibitors, extreme pressure additives and the like. In the absence of air it is quite stable to temperatures of the order of 600-650°F (315-345°C) for extended periods of time. Designed as a jet engine lubricant candidate, MCS 293 possesses outstanding gear lubrication capabilities and is expected to display good fatigue characteristics. Its use is recommended in applications where greater oxidative, thermal or radiation stability is required than can be offered by existing conventional lubricants and where better low-temperature properties are needed than those provided by the polyphenyl ethers. The following are some typical properties of MCS 293.

PHYSICAL PROPERTIES

- Viscosity, Density and Compressibility

Temperature °F	Temperature °C	Viscosity (cs)	Density (g/cc)	Bulk Modulus* (psi)	Bulk Modulus* (kg/cm^2)
0	-18	13,040	-	500,000	35,180
77	25	-	1.195	410,000	28,820
100	38	25.2	1.184	340,000	23,900
210	100	4.13	-	285,000	20,050
300	150	2.0	1.101	230,000	16,200
500	260	0.81	1.017	190,000	13,400
700	370	0.48	0.926		

* Secant, Isothermal 0-7500 psi (0-527 kg/cm^2) range.

- Pour Point -20°F (-25°C)

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- Vapor Pressure

  140 mm Hg at 700°F (371°C)
  760 mm Hg at 795°F (424°C)

- Flammability Properties

Flash Point	445°F (230°C)
Fire Point	540°F (285°C)
Autogenous Ignition Temperature	940°F (500°C)

- Thermal Properties

Temperature °F	Temperature °C	Specific Heat (BTU/lb. °F)	Thermal Conductivity BTU °F ft/hr	Thermal Conductivity $K \times 10^{-5}$ Cal/cm °C sec
0	-18	0.312	0.0677	-
100	38	0.347	0.0714	29.7
200	93	0.383	0.0720	29.6
300	150	0.418	0.0690	28.5
400	200	0.452	0.0650	27.0
500	260	0.488	0.0585	24.2

PERFORMANCE RIG TESTS

- Ryder Gear Scuff Test

at 167°F (75°C)	3020 ppi (average)
at 400°F (200°C)	1350 ppi (average)

- Ryder Gear Fatigue 167°F (75°C)

Pre-endurance Scuff	1.8%
First "A" Pit	100 hours
First "B" Pit	None at 150 hours
Final Scuff	14.1%
Pits at 150 hours	9 "I" pits, 1 "A" pits

- IAE Gear Oil

Reference Oil	% of Reference Oil at 2000 rpm	% of Reference Oil at 6000 rpm
RR 1	76 to 85%	93 to 98%
RR 2	80 to 89%	135 to 141%

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- Bearing Rig Test

	Type 2-1/2	Type 3
Bearing Temperature	550°F (290°C)	600°F (316°C)
Bulk Oil Temperature	500°F (260°C)	550°F (290°C)
Oil Inlet Temperature	450°F (230°C)	500°F (260°C)
After 100 Hours		
Over-all Demerit Rating	40.4	66.1
Change in 100°F(37.8°C) Viscosity	58%	104%
Increase in Acid Number	nil	nil
Consumption Rate	48.6 cc/hr	103 cc/hr
Sludge Formation	1.16 g	8.39 g

BENCH SCALE PERFORMANCE TESTS

- Oxidation-Corrosion Test

(Modified FS 791, Method 5308.2; 48 hours at temperature, 5 L/hr air flow)

Temperature	500°F (260°C)	600°F (315°C)
Weight Change of Metals (mg/cm^2)		
magnesium	+0.03	+0.48
aluminum	0	-0.22
titanium	-0.05	+0.16
iron	+0.04	+0.23
copper	-3.97	-8.37
silver	-0.71	-1.39
Change in Viscosity		
at 100°F (37.8°C)	+6.5%	+42.3%
at 210°F (99.0°C)	+4.4%	+20.8%
Neutralization Number		
Initial	0.01	0.01
Final	0.10	0.15

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Oxidation-corrosion test with copper alloys in lieu of electrolytic copper used in the standard test. All other conditions unchanged. Temperature 500°F (260°C)

	Nickel Silver	Aluminum Bronze #3	Silicone Iron Bronze	Alcop	Phosphor Bronze	Gear Bronze
Metal Weight Change						
Mg	+0.21	-.09	+.32	+0.25	+0.24	+0.19
Al	+0.04	0	+.01	+0.02	+0.01	+0.07
Ti	+0.04	+0.06	+0.06	+0.05	+0.10	+0.08
Fe	+0.13	+0.13	+0.14	+0.15	+0.15	+0.10
Cu alloy	0	+0.66	-1.91	+0.31	-0.15	-0.59
Ag	-0.25	-0.25	-0.17	-0.11	-0.13	-0.24
Fluid Change						
100°F Viscosity	8.9%	12.2%	4.5%	7.0%	7.9%	6.4%
Alloy Composition						
copper	60	85	91.5	62	80	89
tin	2				10	11
lead	6			1	10	
zinc	20		3.5	36		
iron		4	1.2			
aluminum		11		1		
other	Ni(12)		Si(3.5)			Ni(2)

Thermal Stability Test
(Rolls Royce Method #1004)

	250°C	300°C
Volatility (% by wt.)	0	14.1
Insolubles Increase (mg/g)	0.10	0.96
Acidity Increase (mg. KOH/g)	+0.04	+0.05
Kinematic Viscosity Change (%)	0.9	42.1

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- Corrosion Test
  (Rolls Royce Method 1002; "A" Procedure)
  (Conditions: 192 hours at 150°C (302°F)

Specimen	Weight Losses (mg/cm^2)		
	Tube #1	Tube #2	Recheck
Brass	-0.04	-0.17	+0.37
Magnesium	+0.44	+0.49	+0.33
Copper (1)	-0.43	-0.60	-0.57
Aluminum	+0.16	+0.20	+0.24
Copper (2)	-0.51	-0.67	-0.51
Iron	+0.06	+0.14	+0.13
Copper (3)	-0.73	-0.69	-0.80
Soldered Copper	-0.57	-0.37	-0.48
Copper (4)	-0.46	-0.50	-0.23
Lead	-3.57	-3.39	-3.20
Copper	-0.31	-0.34	+0.21

- Thermal Stability Test at 617°F (325°C)
  (D. Eng. R.D. 2487, Issue #4)

Test (Hours)	Viscosity at 100°F (37.8°C)	% Change
0	25.2	-
6	25.5, 25.4	1.2, 0.7
12	25.8, 25.9	2.1, 2.6
18	25.6, 25.6	1.4, 1.4
24	26.2 26.0	3.7, 3.2

No coking, fluid clear, moderate sludge

- Evaporation Loss (ASTM D-972)

500°F (260°C) at 760 mm	50.7% average
500°F (260°C) at 140 mm	61.0% average

- Foam Test

Sequence #1 -	75°F	- tendency	35 ml.
-	(24°C)	- stability	26 sec.
Sequence #2 -	200°F	- tendency	0 ml.
	(93°C)	- stability	0 sec.
Sequency #3 -	75°F	- tendency	60 ml.
	(24°C)	- stability	28 sec.

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COMPATIBILITY CHARACTERISTICS

- Elastomer Swell Test
(Federal Test Method 360.3; 168 hours)

		Durometer "A" Hardness		Volume Swell
158°F (70°C)		Initial	Final	Per Cent
Viton A		74	74	0.46
EPR-E515-8	(1)	76	70	4.88
	(2)	77	70	5.71
Butyl	(1)	71	60	5.91
	(2)	70	60	5.54
Silicone		66	66	0
300°F (150°C)				
Viton A	(1)	74	74	1.05
	(2)	74	74	0.80
EPR-E515-8	(1)	79	65	13.7
	(2)	77	65	13.1
Silicone		66	---Fell Apart---	
400°F (204°C)				
Viton A	(1)	74	74	1.98
	(2)	74	74	3.00
EPR-E515-8	(1)	78	Split	9.28
	(2)	77	Split	8.39

- Lubricants and Hydraulic Fluids

MCS 293 is miscible in all proportions with ester-based turbine lubricants of the Type 1, Type 2, MIL-L-7808, MIL-L-9236, MIL-L-23699, DERD 2487 and DERD 2497. Petroleum-based oils, lubricants or hydraulic fluids are not miscible and contamination should be avoided. Mixtures of MCS 293 with SKYDROL 500A and SKYDROL 7000 are miscible.

TOXICITY

Preliminary screening indicates that this fluid is practically non-toxic when administered orally to rats, percutaneously to rabbits, or by inhalation by rats of vapors produced when the fluid is pyrolyzed on metal surfaces heated to 500°F (260°C) and 700°F (370°C).

MCS 293 is currently available in development quantities. Prices are available upon request. The Ryder Gear Scuff Test, Ryder Gear Fatigue Test, and the Bearing Rig Test were conducted by independent testing laboratories and copies of the reports are available upon request. Details of toxicity evaluations will also be furnished upon request.

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INFLUENCE OF ALLOY ON COPPER ATTACK OF MCS 293 IN A 500°F OXIDATION-CORROSION TEST

Metal Wt. Change	S-Monel	Brasses AMS 4610H	Brasses AMC 4505C	Bronzes Mueller 600 Bronze	Bronzes Phosphor Bronze	Pure Cadmium	Brazing Alloys AMS 4770	Brazing Alloys AMS 4772
Mg	+0.30	+0.24	+0.24	+0.20	+0.13	+0.19	+0.27	+0.20
Al	+0.15	+0.04	+0.10	+0.07	+0.06	+0.06	+0.13	+0.10
Ti	+0.01	+0.02	+0.03	-0.01	+0.01	+0.09	+0.01	+0.02
Fe	+0.03	+0.06	+0.07	+0.03	+0.04	+0.04	+0.07	+0.05
Cu Alloy	+0.08	+0.44	+0.31	+0.24	-2.97	+0.22	+0.38	-0.72
Ag	-0.21	-0.22	-0.33	-0.41	-1.56	-0.30	-0.22	-0.44
Fluid Change								
% Viscosity @ 100°F	12%	10.8%	6.4%	11.0%	10.6%	8.6%	11.7%	14.0%
Alloy Composition								
Copper	30	61.5	70	58	90-98		15.5	40
Tin					2-10			
Silver							50	54
Zinc		35.5	30	37.2			16.5	5
Nickel	63							1
Aluminum				1.5				
Other	(Si) 4	(Pb) 3		(Mn) 2.5 (Si) 0.8		(Cd) 100	(Cd) 18	

Addendum to MCS 293
Technical Data Sheet

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June 1, 1965

TOWOLDMON0030997

MCS 314 and MCS 315

GAS TURBINE LUBRICANTS

DEVELOPMENTAL SYNTHETIC FLUIDS

Preliminary Technical Data Sheet — September 1, 1964

MCS 314 is a specially designed version of the Type 2-1/2 class of lubricants. It was designed to achieve the ultimate in low temperature start-up capability attainable with this class of materials and was achieved by means of compromising the volatility characteristics. The basic physical properties, such as density, bulk modulus, specific heat, thermal conductivity, etc., are virtually identical to that of the parent fluid, MCS 293. The properties peculiar to MCS 314 are listed below.

MCS 315 differs from both MCS 293 and MCS 314 in that it contains aromatic halogenated materials. The presence of this halogenated material enhances the general balance of viscosity and volatility. It is recognized, however, that in certain applications, the presence of halogen is not desirable. The data on MCS 315 are shown below.

- Kinematic Viscosity

Temperature °F	Temperature °C	MCS 314	MCS 315
-37	-39	-	500,000
-30	-34	500,000	-
-20	-29	50,640	15,740
-10	-23	8,100	3,608
100	38	16.24	12.41
210	99	3.11	2.77
350	177	1.14	1.08

- Pour Point — -35°F(-37°C) -40°F(-40°C)

- Evaporation Loss (ASTM D-972)

400°F (204°C) at 760 mm	19.0%	21.3%
450°F (232°C) at 760 mm	53.1%	47.3%

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• Flammability Properties	MCS 314	MCS 315
Flash Point	395°F (200°C)	405°F (207°C)
Fire Point	495°F (257°C)	500°F (260°C)
Autogeneous Ignition Temperature	910°F (490°C)	930°F (500°C)
• Ryder Gear Scuff	2675 ppi	3830 ppi
• Foam Test (ASTM D-892)		
Sequence #1	20 mL 4 sec.	15 ml. 5 sec.
Sequence #2	0 ml. 0 sec.	0 ml. 0 sec.
Sequence #3	10 ml. 3 sec.	15 ml. 3 sec.
• Oxidation-Corrosion Test (FS 791; Method 5308.2, 48 hours, 5 L/hr. air flow at 500°F (260°C)		
Weight Change of Metals		
magnesium	+0.21	-0.20
aluminum	+0.10	+0.07
titanium	+0.02	+0.01
steel	+0.10	+0.07
copper	-6.01	-4.44
silver	-1.19	-1.19
Change in Viscosity		
at 100°F (38°C)	3.9%	9.2%
at 210°F (99°C)	2.0%	5.0%

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- Corrosion Test
(Rolls Royce Method 1002A)

Weight Change (mg/cm^2)	MCS 314	MCS 315
brass	+0.23	-0.01
magnesium	+0.27	+0.20
copper (1)	-0.57	-0.67
aluminum	+0.17	+0.21
copper (2)	+0.93	-0.66
iron	none	+0.06
copper (3)	-0.36	+0.14
soldered copper	+0.37	-0.44
copper (4)	-0.19	-0.14
lead	-4.04	-4.80
copper (5)	-0.04	-0.11

- Thermal Stability Test at 325°C
D. Eng. R. D. 2487, Issue #4)

Test Time (Hours)	Viscosity at 37.8°C cs	% Change	cs	% Change
0	15.71	0	12.35	0
6	15.84	0.82	12.72	3.0
	15.73	0.12	12.65	2.4
12	16.07	2.3	12.82	3.8
	15.92	1.3	12.81	3.7
18	15.86	1.0	12.89	4.4
	15.94	1.5	12.79	3.6
24	15.94	1.5	12.87	4.2
	16.02	2.0	12.97	5.1

No coking, small quantities of sludge, fluid appearance clear

- Thermal Stability
(Rolls Royce Method 1004)

	at 250°C	at 300°C	at 250°C	at 300°C
Volatility (% by wt)	0	20.5	1.0	19.5
Insolubles (mg/g)	0.11	0.4	0.21	0.8
Acidity (mg. KOH/g)	+0.04	+0.06	+0.06	+0.09
Viscosity at 99°C, % Change	0.6	36.7	1.0	48.6

0407760

TOWOLDMON0031000

TYPE 3-1/2 - TYPE 4

0407761

TOWOLDMON0031001

OS-124

GAS TURBINE LUBRICANT

DEVELOPMENTAL SYNTHETIC FLUIDS

Preliminary Technical Data Sheet September 1, 1964

OS-124 is Monsanto's mixed isomeric five-ring polyphenyl ether which was developed for use in high temperature lubricant applications. It is a viscous, clear yellow liquid which possesses extraordinary resistance to degradation from heat, oxygen, radiation, hydrolysis and chemical attack. It is compatible with metals and elastomers commonly used in high temperature applications and, for most intents and purposes, it is physiologically inert and requires no special handling or precautions. A tabulation of the important physical properties of OS-124 is as follows:

- Physical Properties

Viscosity, Density and Compressibility

Temperature °F	°C	Viscosity (cs)	Density (g/ml)	Bulk Modulus (psi)
100	38	363	1.19	390,000
210	99	13.1	1.14	320,000
400	204	2.1	1.06	215,000
500	260	1.2	1.01	180,000
600	316	0.85	0.97	145,000 (est.)
700	370	0.65	0.93	-

Pour Point + 40°F (5°C)

Vapor Pressure

12 mm Hg at 650°F (343°C)
100 mm Hg at 800°F (427°C)
760 mm Hg at 982°F (530°C)

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TOWOLDMON0031002

Heat Transfer Properties

Temperature °F	Temperature °C	Specific Heat (BTU/lb, °F)	Thermal Conductivity (BTU/°F, ft/hr)
100	38	0.368	0.0768
300	150	0.432	0.0702
500	260	0.496	0.0642 (ext.)
700	370	0.560	0.0582 (ext.)

- Flammability Properties

Flash Point	550°F (288°C)
Fire Point	660°F (350°C)
Autogenous Ignition Temperature	1135°F (557°C)*

* Value obtained in air at atmospheric pressure. The AIT increases as either the total pressure or the oxygen content is decreased. In a study conducted by the Explosives Research Laboratory of the Bureau of Mines, an AIT above 1300°F (700°C) was observed at 1/2 atmosphere in air in a stainless steel bomb. The details of this work have been reported in Bureau of Mines, Special Report #3802, 1-27-61.

Navy CFR Compression Ignition Test Ratio = 46:1
(U. S. Naval Engineering Experiment Station)

- Performance Characteristics

The "inertness" of OS-124 makes it particularly well suited for use as a lubricant candidate for advanced-design turbojet engines. Degradation of the oil due to heat and oxidation are relatively slow even at ambients of 600°F (316°C).[1] Even more important, however, is the fact that degradation products are soluble and non-acidic. Consequently, as the oil degrades, it does not produce heavy deposits or corrosive side-products. Even under the severest of conditions (700-750°F (370-400°C) in air), negligible amounts of acids and sludge are formed.

1/ "Antioxidants for High Temperature Lubricants" by Stemniski, Wilson, Smith, & McHugh, ASLE Trans., 1 43-54 (1964)

0407763

TOWOLDMON0031003

The resistance of OS-124 to oxidation can be further enhanced by means of additives.[1] Some additives will, in effect, restrict degradation rates to a level where the inhibited fluid will degrade at 700°F (370°C) at the same rate that the uninhibited fluid will degrade at 600°F (316°C). Bearing test data follow.

Bearing Rig Test

(CRC Procedure)	Base Stock	Inhibited
Bearing Temperature	650°F (343°C)	650°F (343°C)
Bulk Oil Temperature	600°F (316°C)	600°F (316°C)
Oil Inlet Temperature	550°F (288°C)	550°F (288°C)
Over-all Demerit Rating	114	66
Change in 100°F Viscosity	2,000% (82 hrs)	64% (100 hrs)
Acid Number Increase	nil	nil
Consumption Rate (cc/hr)	39	50
Sludge Formation	1.64	3.11

It should be noted that it is natural for all polyphenyl ethers to turn black even after relatively short exposure to air at high temperatures. This is due to the formation of trace quantities of dissolved color bodies and does not indicate any deterioration of performance capability.

Although the additive studies have been extremely promising, no formulated version is offered for sale because we have not yet been able to properly assess all potential corrallary effects of each individual additive. Thus, it is our policy to offer to each specific application our entire additive background and to select the most appropriate formulation for that particular application rather than to offer a limited choice of additive versions. In this manner the lubricant is, in essence, custom designed for the application.

OS-124 has good hydrodynamic lubrication properties and adequate, but not outstanding, lubricant capabilities under boundary conditions.

Ryder Gear Scuff Test

at 167°F (75°C)	2450 $\pm$ 300 ppi
at 400°F (204°C)	1000 $\pm$ 150 ppi

TOWOLDMON0031004

Ryder Gear load-carrying capacity falls off as the temperature is increased to 400°F (204°C). From studies conducted at Southwest Research Institute[2] under Air Force contract with similar five-ring polyphenyl ethers using Nitralloy "N" gears, it would appear that the load-carrying capacity has a minimum at 400°F (204°C). The values thereafter begin to increase again up to 700°F (370°C).

- General Performance Data

Evaporation Loss (ASTM D-972)
6-1/2 hours at 500°F (260°C)

at 140 mm	8% maximum
at 760 mm	4% maximum

Oxidation-Corrosion Test
(Modified FS 791, Method 5308.2; 48 hours at temperature, 5 L/hr air flow)

	Base Fluid	Inhibited	
Temperature	600°F (316°C)	600°F (316°C)	700°F (371°C)
Weight Change of Metals			
magnesium	+0.25	+0.02	0
aluminum	+0.01	+0.01	-
titanium	+0.02	+0.02	-
steel	+0.05	+0.04	-
copper	-0.95	+0.29	-0.03
silver	+0.32	-0.12	-0.02
Change in Viscosity			
at 100°F (378°C)	70	23	89
at 210°F (99°C)	32	17	29

Eppi Seal Wear Test

Rate: 0.53×10^{-5} in/min.; slope: 2.3×10^{-5}

2/ ASD Technical Documentary Report 62-264 Part 1, March 1963 "Development of Lubricant Screening Tests and Evaluation of Lubricants for Gas Turbine Engines for Commercial Supersonic Transport," Baber et al, Sw.R.I. Contract #AF 33(657)-11028.

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TOWOLDMON0031005

Foam Test (ASTM D-892)

Sequence #1 - 75°F - tendency	550 ml.	max.
- (24°C) - stability	480 sec.	max.
Sequence #2 - 200°F - tendency	30 ml.	max.
- (93°C) - stability	8 sec.	max.
Sequence #3 - 75°F - tendency	520 ml.	max.
- (24°C) - stability	440 sec.	max.

Elastomer Compatibility

Most elastomers suitable for high temperature application are compatible with OS-124. The results of tests conducted at 300°F (150°C) for a period of 168 hours are as follows:

	Per Cent Change			
	Specimen A		Specimen B	
	Wt.	Vol.	Wt.	Vol.
Viton Strip (Precision #17107)	-0.46	-0.01	-0.44	-1.64
Viton Strip (Precision #19009)	+0.17	+4.28	+0.14	+0.34
Viton "O" Ring (Precision #17007)	+1.25	0	+1.18	0
Teflon "O" Ring (Precision)	+0.46	0	+0.44	0
Butyl "O" Ring (Precision 112-9077)	-0.01	0	+0.01	+0.11
Silicone "O" Ring (Precision 112-11307)	0	0	0	0

Shell Four-Ball Wear Data(400°F, 204°C)
(scar diameter in mm.)

10 kg load	0.80
30 kg load	0.89
50 kg load	1.13

(600 rpm., 1 hour, 52-100 steel balls)

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B

TOWOLDMON0031006

- Miscellaneous Properties

Critical Properties			Heat of Vaporization	
Temperature	=	1781°F	(670°F to 893°F)	49.2 Cal/gram
Pressure	=	14.2 atmospheres	(354°C to 480°C)	88.6 BTU/pound
Volume	=	1,222 cc/g		
Compressibility	=	0.25		

Electrical Properties	60 cy	1 kc	10 kc	100 kc
Dielectric Constant				
at 25°C	4.47	4.47	4.47	4.47
at 100°C	3.89	3.89	3.88	3.88
Power Factor				
at 25°C	0.05	0.01	0.03	0.22
at 100°C	2.03	0.09	0.01	0.01

Resistivity

at 25°C	at 500 VDC	7400×10^9	ohm-cm.
at 100°C	at 500 VDC	2800×10^9	ohm-cm.

Surface Tension — 49.9 dynes/cm.

Interfacial Tension (vs. water) — 12.9 dynes/cm.

Refractive Index — μ_D^{25} 1.6306

- Toxicity

The results of animal research studies with OS-124 indicate that this material demonstrates a very low order of toxicity. The oral lethal dose for both rats and rabbits was found to be greater than 34.6 grams per kilogram. When applied to the unbroken skin of rabbits, the animals survived dosages up to 34.6 grams per kilogram. In skin and eye irritation potential studies, the results with rabbits indicated that the material is nonirritating. Rats survived a four-hour exposure to an atmosphere saturated with vapors when the fluid was heated to 625°F. When animals were exposed for four hours to a mixture of air plus vapors and pyrolytic products of the material obtained by dropping the fluid on a metal surface heated to a temperature of 850°F, two of the ten rats exposed expired 48 hours after the exposure had been ended. Surviving rats appeared normal 48-72 hours following the exposure.

0407767

TOWOLDMON0031007

OS-138

GAS TURBINE LUBRICANTS

Preliminary Technical Data Sheet — January 1, 1965

Monsanto's six-ring polyphenyl ether is chemically identified as bis (m-(m-phenoxyphenoxy)phenyl) ether and is designated OS-138. This clear, slightly yellow, viscous liquid possesses the exceptional resistance to degradation from heat, oxygen, and radiation that is typical of the polyphenyl ethers. Its most outstanding feature is its exceptionally low vapor pressure at what are considered "normal" temperatures. It boils at atmospheric pressure at a temperature over 1,000°F. Reflecting this low volatility, it has an exceptionally high flash and fire point. Its AIT of almost 1200°F is one of the highest known. Since the major differences between the four-, five-, and six-ring polyphenyl ethers lie in their viscosity and volatility characteristics, performance properties are generally quite similar for all. Consequently, additional information supplied for OS-124 and MCS 210 can be reasonably extrapolated to OS-138. The following data on OS-138 can be considered typical.

- Viscosity and Density

Temperature °F	Temperature °C	Viscosity (cs)	Density (g/cc)
100	37.8	1,916	1.21
210	99	24.8	1.16
400	204	3.0	1.08
700	371	0.8	0.94

- Pour Point 50°F - 60°F

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TOWOLDMON0031008

- Vapor Pressure

1 mm Hg at	600°F (316°C)
10 mm Hg at	725°F (385°C)
100 mm Hg at	867°F (464°C)
760 mm Hg at	1016°F (546°C)

- Flammability Properties

Flash Point	620°F (327°C)
Fire Point	750°F (400°C)
Autogenous Ignition Temperature	1170°F (577°C)

- Evaporation Loss (ASTM D-972)

400°F (204°C)	at 760 mm	0.04%
500°F (260°C)	at 760 mm	0.50%
500°F (260°C)	at 140 mm	1.10%

- Oxidation-Corrosion Test
(FS-791 Method 5308.2, 48 hours at temperature, 5 L/hr air flow)

Temperature	500°F (260°C)	600°F (316°C)
Weight Change of Metals		
magnesium	-0.01	+0.12
aluminum	-0.02	0
titanium	-0.01	+0.01
steel	-0.01	+0.03
copper	+0.02	-0.20
silver	-0.01	+0.89
Change in Viscosity		
at 100°F (37.8°C)	+2.2%	+94.3
at 210°F (99°C)	+0.5%	+30.7

- Surface Tension 54.2 dynes/cm. at 25°C

TOWOLDMON0031009

- Elastomer Compatibility (at 300°F, 168 hours)

Hardness (Durometer "A")	Viton	Silicone	Butyl	EPR
Initial	64	71	65	70
Final	63	73	Brittle	79
Weight Increase (%)	0.37	-0.43	-	-3.9
Volume Increase (%)	0.35	-1.3	-	-10.9

- Foaming (ASTM D-892)

Sequence #1 -	75°F (24°C) -	tendency	0 ml.
		stability	0 sec.
Sequence #2 -	200°F (93°C) -	tendency	25 ml.
		stability	5 sec.
Sequence #3 -	75°F (24°C) -	tendency	0 ml.
		stability	0 sec.

- Toxicity

The toxicity of this material has not been studied in detail. However, all information obtained or reported thus far indicates quite similar behavior for all of the polyphenyl ether series. The data reported for OS-124, Monsanto's five-ring polyphenyl ether is cited below.

The results of animal research studies with OS-124 indicate that this material demonstrates a very low order of toxicity. The oral lethal dose for both rats and rabbits was found to be greater than 34.6 grams per kilogram. When applied to the unbroken skin of rabbits, the animals survived dosages up to 34.6 grams per kilogram. In skin and eye irritation potential studies, the results with rabbits indicated that the material is non-irritating. Rats survived a four-hour exposure to an atmosphere saturated with vapors when the fluid was heated to 625°F. When animals were exposed for four hours to a mixture of air plus vapors and pyrolytic products of the material obtained by dropping the fluid on a metal surface heated to a temperature of 850°F, two of the ten rats exposed expired 48 hours after the exposure had been ended. Surviving rats appeared normal 48-72 hours following the exposure.

0407770

TOWOLDMON0031010

MCS 210

GAS TURBINE LUBRICANT

DEVELOPMENTAL SYNTHETIC FLUIDS

Preliminary Technical Data Sheet — September 1, 1964

MCS 210 is Monsanto's mixed isomeric four-ring polyphenyl ether. It is a clear, slightly yellow liquid possessing the exceptional resistance to degradation from heat, oxygen, radiation and hydrolysis that is typical of the polyphenyl ethers as a class. It is quite similar in its performance characteristics to the five-ring compound and the information supplied for OS-124 will apply also to MCS 210. The major difference between the four- and five-ring polyphenyl ethers lies in viscosity and volatility characteristics and the properties which relate to them. Typical data on MCS 210 are shown below.

- Viscosity and Density

Temperature °F	Temperature °C	Viscosity (cs)	Density (g/cc)
10	-12	Pour Point	
28	- 2	13,000	
100	37.8	63.2	1.17
210	99	6.0	1.12
400	204	1.31	1.04
700	371	0.48	0.90

- Vapor Pressure

1 mm Hg at 410°F (210°C)
10 mm Hg at 520°F (270°C)
100 mm Hg at 680°F (360°C)
760 mm Hg at 860°F (460°C)

- Flammability Properties

Flash Point	500°F (260°C)
Fire Point	540°F (282°C)
Autogenous Ignition Temperature	1140°F (616°C)

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TOWOLDMON0031011

- Specific Heat

	Cal/g/°C or BTU/lb/°F
100°F (38°C)	0.36
200°F (93°C)	0.40
300°F (150°C)	0.43
500°F (260°C)	0.50
700°F (370°C)	0.56

- Evaporation Loss (ASTM D-972)

400°F (204°C)	at 760 mm	3.4%
450°F (232°C)	at 760 mm	14.8%
500°F (260°C)	at 760 mm	43.1%
500°F (260°C)	at 140 mm	59.2%

- Oxidation-Corrosion Test
(FS-791 Method 5308.2, 48 hours at temperature, 5 L/hr air flow)

Temperature	500°F (260°C)		600°F (316°C)
Weight Change of Metals			
magnesium	-0.06	0	+0.02
aluminum	+0.01	-0.02	0
titanium	+0.01	-0.02	0
steel	+0.03	-0.01	+0.04
copper	-0.01	+0.03	+0.19
silver	-0.05	+0.04	0
Change in Viscosity			
at 100°F (37.8°C)	1.9%	2.7%	10.0%
at 210°F (99°C)	1.3%	1.5%	5.3%

- Ryder Gear Scuff Load — 2080 ppi (average)

- Gear Fatigue (100 hours)

Pre-endurance Scuff	56.1%
First "A" Pit	50 hours
First "B" Pit	-
Final Scuff	61.4%
Final Pits	20 "I" pits, 8 "A" pits, no "B" pits

TOWOLDMON0031012

- Bearing Rig Test

Bearing	550°F (288°C)
Bulk Oil	500°F (260°C)
Oil Inlet Temperature	450°F (232°C)

After 100 Hours

Over-all Demerit Rating	49.3
Change in 100°F Viscosity	50%
Change in Acid Number	nil
Consumption Rate	39.2 cc/hr
Sludge Formation	2.2 g

- Foam Test (ASTM D892-63)

Sequence #1	75°F	tendency	145 ml.
	(24°C)	stability	102 sec.
Sequence #2	200°F	tendency	0 ml.
	(93°C)	stability	0 sec.
Sequence #3	75°F	tendency	220 ml.
	(24°C)	stability	218 sec.

- Miscellaneous Properties

Refractive Index	1.6219
Surface Tension	44.9 dynes/cm.

- Elastomer Compatibility
(Federal Test Method 360.3; 168 hours, 300°F(150°C)).

Hardness	Viton	Silicone	Butyl	EPR
Durometer A				
Initial	65	69	65	69
Final	63	72	Brittle	Brittle
% Weight Increase	0.49%	-0.43%	-	8.8%
% Volume Increase	0.81%	-1.3 %	-	3.6%

TOWOLDMON0031013

- Toxicity

The toxicity of this material has not been studied in detail. However, all information obtained or reported thus far indicate quite similar behavior to the other polyphenyl ethers. The data reported for OS-124, Monsanto's five-ring polyphenyl ether is cited below.

The results of animal research studies with OS-124 indicate that this material demonstrates a very low order of toxicity. The oral lethal dose for both rats and rabbits was found to be greater than 34.6 grams per kilogram. When applied to the unbroken skin of rabbits, the animals survived dosages up to 34.6 grams per kilogram. In skin and eye irritation potential studies, the results with rabbits indicated that the material is non-irritating. Rats survived a four-hour exposure to an atmosphere saturated with vapors when the fluid was heated to 625°F. When animals were exposed for four hours to a mixture of air plus vapors and pyrolytic products of the material obtained by dropping the fluid on a metal surface heated to a temperature of 850°F, two of the ten rats exposed expired 48 hours after the exposure had been ended. Surviving rats appeared normal 48-72 hours following the exposure.

TOWOLDMON0031014

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TOWOLDMON0031015

MCS 232

GAS TURBINE LUBRICANT

DEVELOPMENTAL SYNTHETIC FLUIDS

Preliminary Technical Data Sheet — September 1, 1964

MCS 232 is a clear, amber fluid with exceptionally high thermal and oxidative stability which has been specially designed for industrial or non-airborne lubricant applications. While its viscosity-volatility properties virtually preclude its use at high altitudes, its outstanding stability would qualify it as a "lifetime" lubricant in industrial turbines, compressors and similar applications. Its characteristic fluid properties are as follows:

Temperature		Vapor Pressure	Viscosity		Density	
°F	°C	(mm Hg)	(cs)	(Lbs/ft/hr)	(GMS/cc)	(Lbs/Gal)
100	38	-	181	505	1.152	9.60
210	99	-	7.78	20.8	1.106	9.22
300	150	0.27	-	-	-	-
400	204	1.03	1.50	3.74	1.029	8.58
500	260	9.2	0.96	2.28	0.981	8.16
600	316	44	0.66	1.49	0.931	7.76
700	371	168	0.46*	0.99	0.885	7.38
800	427	530	-	-	-	-

Temperature		Specific Heat	Thermal Conductivity	
°F	°C	(BTU/Lb.)	(Cal/cm °C sec)	(BTU/°F ft/hr)
100	38	0.350	32.25×10^{-5}	0.0781
200	93	0.385	31.40×10^{-5}	0.0760
300	150	0.420	30.50×10^{-5}	0.0739
400	204	0.455	29.65×10^{-5}	0.0719
500	260	0.495	28.80×10^{-5}	0.0698
600	316	0.530	--	--
700	371	0.565	--	--
800	427	0.600	--	--

* Extrapolation

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TOWOLDMON0031016

- Pour Point + 50°F (10°C)
- Flash Point 465°F (240°C)
- Fire Point 545°F (285°C)
- A.I.T. 1110°F (600°C)
- Thermal Decomposition** 795°F (425°C)
- Shell Four-Ball Wear (400°F (204°C), 626 rpm, 1 hour)

(steel)		(steel)
52-100	on	52-100

10 kg. - 1.46 mm scar dia.
30 kg. - 1.63 mm scar dia.
50 kg. - 1.43 mm scar dia.

- Oxidation-Corrosion Test
(MIL-L-9236A Method, 48 hours at 450°F (232°C) and 500°F (260°C), air)

		450°F(232°C)	500°F(260°C)
% Viscosity Increase at	100°F(37.8°C)	52	49
	210°F(99°C)	17	17
Metal Weight Loss, mg/cm^2			
	Cu	-0.58	-1.06
	Fe	+0.01	-0.01
	Mg	None	+0.64
	Ag	-0.28	+0.09
	Ti	-0.01	+0.01
	Al	None	None

- Ryder Gear Scuffing Load

Lbs./in. of face 2250

- Evaporation Loss (6-1/2 hours)
(Sea Level (760 mm Hg)

at 400°F (204°C)	15%
at 450°F (232°C)	30%
at 500°F (260°C)	53%

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** Thermal decomposition was determined by the isoteniscope method as described in the "Journal of Chemical & Engineering Data," January, 1961, Vol. 6, No. 1. It is defined as the temperature at which dp/dt=0.014 mm Hg per sec. or 500 mm Hg per 10 hours.

TOWOLDMON0031017

- Foam Test

Sequence #1	- 75°F -	tendency	0 ml.
	- (24°C) -	stability	0 sec.
Sequence #2	- 200°F -	tendency	0 ml.
	- (93°C) -	stability	0 sec.
Sequence #3	- 75°F -	tendency	10 ml.
	- (24°C) -	stability	15 sec.

- Toxicity and Safe Handling

Appropriate animal toxicity studies indicate that MCS 232 is "practically non-toxic" from the standpoint of accidental swallowing or single massive skin exposures. Irritation potential studies indicate that it should not be irritating to the skin and only slightly irritating to the eyes if there is accidental contact. Animals survived a single four-hour exposure to an atmosphere saturated with vapors at room temperature. It appears that no particular safety precautions are necessary during the handling of this fluid at room temperature.

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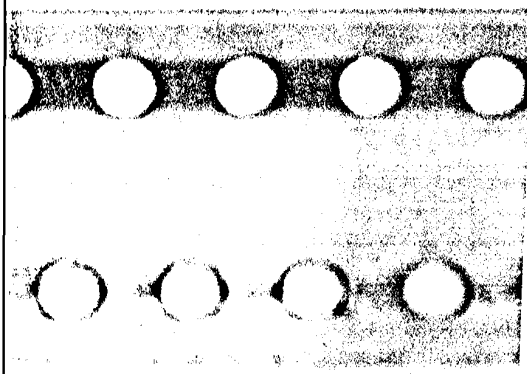

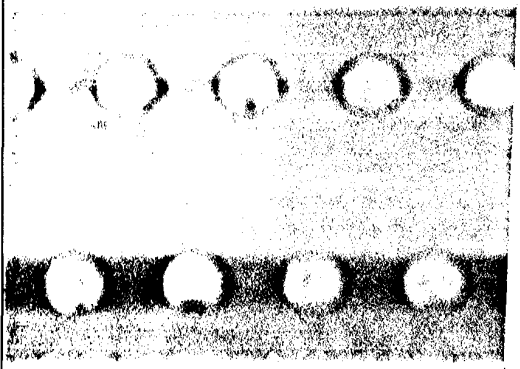

Bottles

WIDE-Mouth

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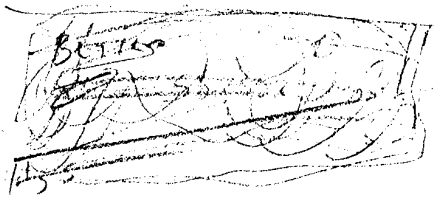

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ANNUAL REVIEW

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