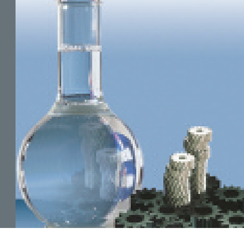
ExxonMobil Chemical

Synthetic Lubricant Basestocks

Formulations Guide

**Step Up Your Lube Innovation
With Our Products and Technology**



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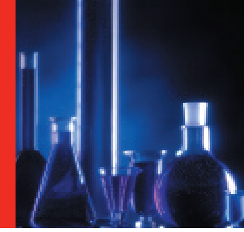


USING THIS GUIDE

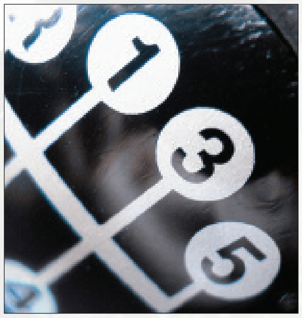
Formulators using synthetic basestocks are being asked to create more sophisticated and advanced lubricants everyday. This *Synthetic Basestocks Formulations Guide* can provide a head start in developing lubricant formulations and offers assistance in making the best basestock choices for many lubricant applications.

The Formulations Guide provides a handy reference source to quickly identify the performance characteristics of ExxonMobil Chemical's entire family of synthetic basestocks – SpectraSyn™, SpectraSyn Plus™ and SpectraSyn Ultra™ Polyalphaolefins (PAO) fluids, Synesstic™ Alkylated Naphthalene (AN) fluids, and Esterex™ synthetic fluid*. This Guide also takes the evaluation of synthetic basestocks a step further through recommending the optimal combination for a given lubricant viscosity grade. These basestock combinations represent many of the core industrial and automotive synthetic lubricant formulations, from passenger car engines to compressors and hydraulic systems.

You may find right on these pages a basestock formulation and, in some cases, an additive package that works for you. At a minimum, we think you'll find a starting point from which to advance your formulation efforts. Either way, you can count on the support of your ExxonMobil Chemical sales representative and our entire Synthetics team.

Ready to save time and money and put your applications development on a fast track? Just turn the page and get started.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.



LUBE FORMULATOR FAQs

Q: Why use Synthetics Fluids?

A: Synthetics Lubricants can provide that high-performance edge. Composed of molecules with near ideal properties including high purity, uniformity, and stability, they have an almost perfect service behavior free from typical mineral oil constraints. Performance advantages can include; a wider operational temperature range, stability under severe conditions, and extended fluid service life.

Q: Why should I choose ExxonMobil Chemical and its synthetic lubricant basestocks?

A: ExxonMobil Chemical is the premier producer of both Group IV and Group V synthetic basestocks, including a complete viscosity range of polyalphaolefins (2 - 1000 cSt), novel alkylated naphthalene products and a line of ester products*. This broad portfolio gives us the comprehensive understanding of synthetic lubricant formulations that is necessary to help our customers develop innovative and marketable products.

Q: How can this Formulations Guide help me?

A: This Guide is intended to provide the formulator with a head start in developing synthetic lubricant products. It minimizes the need for extensive basestock screening through recommending the optimal basestock combination for a given viscosity grade in a lubricant application. This Guide can help you increase your speed to market by reducing your product development time.

Q: What type of lubricant applications does this Guide include?

A: This Guide includes synthetic basestock recommendations for most core automotive and industrial lubricant applications. These recommendations are designed to meet the standard viscosity grades for each lubricant application.

Q: How much variability is there in the formulation recommendations?

A: Very little. The basestock combinations listed in the Guide should achieve the specified viscosity grade and performance level.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Q: Have the formulations listed in this Guide been validated through testing?

A: This Guide contains some formulations with specific additive recommendations and shows additional performance testing. These tests have also been validated in laboratory testing. As with all formulations, however, some adjustment may be required to meet specific formulation requirements.

Q: Are the formulations in this Guide representative of a finished lubricant?

A: They are intended to be starting-point formulations based exclusively on ExxonMobil Chemical basestocks. In some cases, we've also recommended specific additive packages so that when properly formulated, the result could be a finished lubricant. In other cases, we are recommending a basestock combination to achieve a specific viscosity grade, with the additive choice left to the preference of the formulator.

Q: Can I substitute additives I may already be using for the additive packages shown in the Guide?

A: Where specific additives are recommended, it is because they are in common use and commercially available. We're not recommending any one additive over another, and you may achieve a better result with a different additive. We are providing the recommendations as examples.

Q: Can I obtain a product sample?

A: Product samples are available for all of our synthetic basestocks. Please contact your ExxonMobil Chemical sales representative to make arrangements. Or visit our Web site at **www.exxonmobilsynthetics .com** for a complete listing of our global sales offices.

Q: Can I use these basestocks in applications not listed here?

A: Our synthetic basestocks can be used in a wide variety of applications, from engine oils to personal care products to textile lubricants. They may also be useful in other applications not covered in this Guide. Our technical support staff is available to help with formulation recommendations beyond those covered in this Guide; please contact your ExxonMobil Chemical sales representative for assistance.

Q: What other services are available to me as a potential customer?

A: ExxonMobil Chemical offers numerous value-added services to its customers, including formulation assistance, performance testing, product development assistance, and global product registration.

Q: Where can I get information on the health and safety characteristics of these products?

A: Material Safety Data Sheets (MSDS) are available for each synthetic basestock product and can be obtained through your ExxonMobil Chemical sales representative.

Q: Do you have any formulations based on mineral oil?

A: Many of our synthetic basestock products can be used with mineral oils to enhance their overall effectiveness. Our technical support staff can help design a semi-synthetic base-stock recommendation, should you have a specific interest.

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Q: My application may require just a single drum of your synthetic basestocks. Can you supply me at that level?

A: With the assistance of our extensive secondary distribution network, we are able to accommodate needs in various package sizes.

Q: Will this Guide be updated to reflect new information and technology?

A: Since we are continually updating our product data and technology, we will update this Guide periodically as warranted.

Alkylated Naphthalene Blendstocks – Product Properties

	Synesstic™ 5	Synesstic™ 12
Specific Gravity @ 15.6/15.6°C	0.908	0.887
Viscosity @ 100°C, cSt	4.7	12.4
Viscosity @ 40°C, cSt	29	109
Brookfield Viscosity @ -26°C, cP	3,950	22,000
Color, ASTM	<1.5	<4.1
Viscosity Index	74	105
Flash Point, Open Cup, °C	222	258
Pour Point, °C	-39	-36
Noack Volatility, weight % loss	12.7	4.5
Total Acid Number, mg KOH/g	<0.05	<0.05

Note: cSt=mm^2/s, cP=mPa-s

Polyalphaolefin Basestocks – Product Families

ExxonMobil Chemical Products	SG@ 15.6/ 15.6°C	KV@ 100°C cSt	KV@ 40°C cSt	KV@ -40°C cSt	VI	Pour Pt. °C	Flash Pt. COC °C	Noack Volatility Wt. %
SpectraSyn™ 2	0.798	1.7	5	252	–	-66	157	–
SpectraSyn™ 2B	0.799	1.8	5	–	–	-54	149	–
SpectraSyn™ 2C	0.798	2.0	6.4	–	–	-57	>150	–
SpectraSyn™ 4	0.820	4.1	19	2,900	126	-66	220	14
SpectraSyn™ 5	0.824	5.1	25	4.920	138	-57	240	6.8
SpectraSyn™ 6	0.827	5.8	31	7,800	138	-57	246	6.4
SpectraSyn™ 8	0.833	8.0	48	19,000	139	-48	260	4.1
SpectraSyn™ 10	0.835	10.0	66	39,000	137	-48	266	3.2
SpectraSyn™ 40	0.850	39	396	–	147	-36	281	–
SpectraSyn™ 100	0.853	100	1,240	–	170	-30	283	–
SpectraSyn Plus™ 3.6	0.816	3.6	15.4	2,000	120	<-65	224	<17
SpectraSyn Plus™ 4	0.820	3.9	17.2	2,430	126	<-60	228	<12
SpectraSyn Plus™ 6	0.827	5.9	30.3	7,400	143	<-54	246	<6
SpectraSyn Ultra™ 150	0.850	150	1,500	–	218	-33	≥265	–
SpectraSyn Ultra™ 300	0.852	300	3,100	–	241	-27	≥265	–
SpectraSyn Ultra™ 1000	0.855	1,000	10,000	–	307	-18	≥265	–

Note: cSt=mm^2/s

Ester Basestocks – Product Descriptions*

Product Type		Chemistry	ExxonMobil Chemical Products
Dibasic Esters	Adipate	Diisooctyl	Esterex™ A32*
		Diisononyl	Esterex™ A34*
		Diisodecyl	Esterex™ A41*
		Ditridecyl	Esterex™ A51*
Aromatic Esters	Phthalate	Diisoheptyl	Esterex™ P35*
		Diisodecyl	Esterex™ P61*
		Ditridecyl	Esterex™ P81*
	Trimellitates	Triisooctyl	Esterex™ TM101*
		Triisononyl	Esterex™ TM111*
Polyol Esters		TMP C_8/C_{10}	Esterex™ NP343*
		PE Ester	Esterex™ NP451*

Ester Basestocks – Product Families*

ExxonMobil Chemical Products	SG@ 15.6/ 15.6°C	KV@ 100°C cSt	KV@ 40°C cSt	VI	Pour Pt. °C	Flash Pt. COC °C	Color ASTM	Water, ppm	TAN, mg KOH/g	Bio-degrad-ability (OECD 301, F %[b])
Esterex™ A32*	0.928**	2.8	9.5	149	-65	207	<0.5	<500	<0.08	70.2
Esterex™ A34*	0.922**	3.2	12	137	-60	199	<0.5	<1000	<0.08	78.5
Esterex™ A41*	0.921	3.6	14	144	-57	231	<0.5	<500	0.01	76.5
Esterex™ A51*	0.915	5.4	27	136	-57	247	<0.5	<350	0.02	58.5
Esterex™ P35*	0.944**	3.5	18	47	-45	199	<0.05	<1000	<0.07	–
Esterex™ P61*	0.967**	5.4	38	62	-42	224	<0.5	<1000	<0.07	71.4
Esterex™ P81*	0.955**	8.3	84	52	-33	265[b]	<0.5	<1000	<0.14	54.5
Esterex™ TM101*	0.990**	9.8	89	86	-36	259[b]	<0.5	<1000	<0.16	<1
Esterex™ TM111*	0.978**	11.9	124	81	-33	274[b]	<0.5	<1000	<0.16	<1
Esterex™ NP343*	0.945	4.3	19	136	-48	257	0.5	<350	0.02	76.4[a]
Esterex™ NP451*	0.993	5.0	25	130	-60	255	<0.5	<500	0.01	84

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

**At 20/20°C Note: cSt=mm^2/s (a) OECD 301B (b) Single sample or two sample average determinations

PASSENGER CAR ENGINE

Lubricant Application

Engine oils are composed of basestocks and additives. Engine oils provide crucial protection for all the working parts of internal combustion engines. The main purpose of a lubricating engine oil is to provide an unbroken film of molecules that prevents metal contact and reduces friction inside an engine. Lubrication is accomplished by a combination of differential pressure supplied by the oil pump for the top of the engine and by splash lubrication supplied by the crankshaft for the lower half of the engine. The engine oil is expected to provide the following key benefits:

- *Remove heat and wear particles*
- *Reduce corrosion by neutralizing combustion products*
- *Improve fuel economy and reduce emissions*

Relative to mineral oils, use of synthetic basestocks in automotive lubricants provides improved wear protection, lower volatility, and better thermal and oxidative stability. These results translate to extended drain intervals relative to mineral oil and to fuel economy benefits. The two synthetic basestock types which will be discussed in this document are polyalphaolefins (PAO) and alkylated naphthalene (AN).

Lubricant Requirements

The highest performance standards for engine oils can be met using synthetic basestocks such as SpectraSyn™, SpectraSyn Plus™ PAO and Synesstic™ AN. These chemically derived synthetic basestocks offer numerous advantages over mineral oil basestocks, such as:

- *Better oxidative and thermal stability for long service life*
- *Better volatility for reduced engine oil emissions*
- *No inherent contaminants to accelerate corrosion or acid formation*
- *Higher saturates level for greater soot-handling capabilities*
- *Lower pour points for improved operational low temperatures*

The suggested engine oil formulations described on the following page provide a basic guideline to developing various engine oil grades based on ExxonMobil Chemical's SpectraSyn™ PAO and Synesstic™ AN. While no formal engine oil license performance (i.e., API ILSAC GF-4/SM, ACEA A1/B1, ... A5/B5) is implied or guaranteed in these formulations, the key physical properties as defined by SAE J300 are met, and should provide a good starting point for lubricant formulators.

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Engine Oil Blends with SpectraSyn™

SAE Viscosity Grade	0W-30		5W-30		10W-30	
Formulation:	**Weight %**		**Weight %**		**Weight %**	
SpectraSyn™ 4	53		17			
SpectraSyn™ 6	16		53		15	
SpectraSyn™ 8					59	
Synesstic™ 5	10		10		10	
Infineum P5069 Additive Package	11.5		11.5		11.5	
Infineum SV277 Viscosity Modifier	9.5		8.5		4.5	
Properties		**Spec.**		**Spec.**		**Spec.**
KV @ 100°C, cSt	11.10	9.3 - <12.5	11.75	9.3 - <12.5	11.60	9.3 - <12.5
KV @ 40°C, cSt	61.48		68.44		73.07	
Viscosity Index	175		168		153	
Pour Point, °C	-48		-45		-42	
CCS @ -25°C, cP					3,979	7,000 max
CCS @ -30°C, cP			3,716	6,600 max	6,768	6,600 min
CCS @ -35°C, cP	4,795	6,200 max	6,596	6,200 min		
MRV-TP1 @:						
-30°C, cP					8,484	60,000 max
Yield Stress, Pa					<35	<35
-35°C, cP			10,118	60,000 max		
Yield Stress, Pa			<35	<35		
-40°C, cP	14,615	60,000 max				
Yield Stress, Pa	<35	<35				
HTHS @ 150°C, Apparent Viscosity, cP	2.99	2.9 min	3.19	2.9 min	3.28	2.9 min

SAE Viscosity Grade	0W-40		5W-40		10W-40	
Formulation:	**Weight %**		**Weight %**		**Weight %**	
SpectraSyn™ 4	43.5					
SpectraSyn™ 6	23		45		10	
SpectraSyn™ 8			25		61.5	
Synesstic™ 5	10		10		10	
Infineum P5069 Additive Package	11.5		11.5		11.5	
Infineum SV277 Viscosity Modifier	12		8.5		7	
Properties		**Spec.**		**Spec.**		**Spec.**
KV @ 100°C, cSt	13.46	12.5 - <16.3	13.25	12.5 - <16.3	13.47	12.5 - <16.3
KV @ 40°C, cSt	79.96		81.80		86.47	
Viscosity Index	179		164		158	
Pour Point, °C	-45		-42		-42	
CCS @ -25°C, cP					4,330	7,000 max
CCS @ -30°C, cP			5,324	6,600 max	7,343	6,600 min
CCS @ -35°C, cP	5,367	6,200 max	9.901	6,200 min		
MRV-TP1 @:						
-30°C, cP					9,886	60,000 max
Yield Stress, Pa					<35	<35
-35°C, cP			14,658	60,000 max		
Yield Stress, Pa			<35	<35		
-40°C, cP	21,086	60,000 max				
Yield Stress, Pa	<35	<35				
HTHS @ 150°C, Apparent Viscosity, cP	3.37	2.9 min	3.55	2.9 min	3.68	2.9 min

Note: cSt=mm²/s; cP=mPa-s

ExxonMobil Data

SpectraSyn Plus™ Advanced Polyalphaolefins

SpectraSyn Plus™ polyalphaolefins (PAO) are high-performance API Group IV fluids manufactured through a proprietary process. Compared to conventional Group IV PAO, SpectraSyn Plus™ PAO provide a superior combination of low volatility and low-temperature fluidity. It is this combination of low volatility and low-temperature fluidity that enables formulators and blenders to improve their lubricants.

SpectraSyn Plus™ PAO can provide low temperature and volatility credits to compensate for Group III and Group II+ basestocks and additive packages in top-tier engine oil applications. SpectraSyn Plus™ PAO can be used to formulate top-tier engine oil formulations as well as other high-performing automotive, aviation and military applications requiring excellent volatility and low-temperature performance.

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Mineral Oil Blends with SpectraSyn Plus™

0W-XX Blends
SpectraSyn Plus™ with Group III

SAE Viscosity Grade	0W-30		0W-40	
Formulation:	**Weight %**		**Weight %**	
Yubase 4	55.0		50.0	
SpectraSyn Plus™ 4	15.9		27.2	
SpectraSyn Plus™ 6	10.0			
Infineum – DDI	12.9		12.9	
Infineum – Friction Modifier	0.5		0.5	
Infineum – VII	5.7		9.4	
Properties		**Spec.**		**Spec.**
KV @ 100°C, cSt	9.5	9.3 - <12.5	12.6	12.5 - <16.3
KV @ 40°C, cSt	52.0		69.8	
Viscosity Index	170		182	
Pour Point, °C	-39		-36	
CCS @ -35°C, cP	5,978	6,200 max	5,950	6,200 max
MRV-TP1 @ -40°C, cP	27,009	60,000 max	34,711	60,000 max
HTHS @ 150°C, cP	2.9	2.9 min	3.4	2.9 min
Yield Stress, Pa	<35	<35	<35	<35
Noack, %	11.3		11.8	

0W-XX Blends
SpectraSyn Plus™ with Group II+

SAE Viscosity Grade	0W-30		0W-40	
Formulation:	**Weight %**		**Weight %**	
EHC 45	35.0		30.0	
SpectraSyn Plus™ 4	31.0		47.2	
SpectraSyn Plus™ 6	15.0			
Infineum – DDI	12.9		12.9	
Infineum – Friction Modifier	0.5		0.5	
Infineum – VII	5.7		9.4	
Properties		**Spec.**		**Spec.**
KV @ 100°C, cSt	10.1	9.3 - <12.4	12.7	12.5 - <16.3
KV @ 40°C, cSt			71	
Viscosity Index			181	
Pour Point, °C				
CCS @ -35°C, cP	6,079	6,200 max	5,579	6,200 max
MRV-TP1 @ -40°C, cP	24,473	60,000 max	26,647	60,000 max
HTHS @ 150°C, cP	3	2.9 min	3.4	2.9 min
Yield Stress, Pa	<35	<35	<35	<35
Noack, %	10		10	

ExxonMobil Data

SpectraSyn Ultra™ High VI PAO

Further enhancement of the performance of synthetic engine oils can be achieved through the use of the SpectraSyn Ultra™ series of extra-high-VI polyapha-olefins, which can provide additional wear protection and VI improvement.

Additive Requirements

Additive packages for engine oil formulations are carefully balanced combinations of individual components, with the treat rates determined by the demands of the lube specification. Generally, viscosity modifiers are also required, and the treat rates are determined by the viscosity targets and basestock properties. The specific additive types used in engine oil formulations are:

Dispersants	*Corrosion Passivators*
Detergents	*Antifoamants*
Rust Inhibitors	*Viscosity Modifiers*
Oxidation Inhibitors	*Friction Modifiers*

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

TWO-STROKE ENGINE

Lubricant Applications
Two-stroke engines are used in a wide range of applications, including outboard engines, motor scooters, snowmobiles, and a variety of lawn and garden equipment such as chainsaws, string trimmers, and snow blowers. The two-stroke oil is added to the engine either premixed with the fuel or via an oil injection system. For premixed fuel oil systems, the owner's manual will guide the user to the recommended fuel:oil ratio. This ratio can range from 16:1 to 50:1. (Fuel:oil ratios for oil injection systems will vary depending on engine speed.)

There are two types of two-stroke oils based on different additive chemistries:

> ***Low Ash:*** *Used in motor scooters, lawn and garden equipment, and some snowmobiles and personal watercraft.*
>
> ***Ashless:*** *Used in NMMA TC-W3™ outboard engine oils, and some snowmobiles and personal watercraft.*

Synthetic two-stroke oils provide the ultimate protection for two-stroke engines, which tend to run very hot. The pistons expand at high temperatures, thus decreasing the piston-to-cylinder wall clearance. This increases engine friction and the possibility of piston scuffing, which could ultimately lead to reduced power and/or engine seizure. The superior lubricity protection of synthetic basestocks in the thin film boundary layer of oil separating the piston and cylinder wall can provide improved engine performance.

Another important consideration for a two-stroke oil is the need to burn cleanly, thereby minimizing deposit formation and visible smoke exhaust. This cleanliness is vitally important to prevent carbon buildup, which leads to ring sticking and spark plug fouling.

Lubricant Requirements
Ester lubricants offer a number of advantages over mineral oils as the lubricant choice for two-stroke engine mixtures. Formulations based on synthetic basestocks, such as esters, are used to improve performance and to allow for potentially higher fuel-to-oil ratios.

The superior quality of synthetic lubricants can provide maximum protection and outstanding performance in two-stroke gasoline engines. Synthetic two-stroke oils can be designed for reduced smoke, reduced carbon buildup, cooler-running engines (less friction), and easier start-ups. Synthetics may also allow for leaner burn ratios, which can provide increased power output for the engine.

In addition, the low-temperature properties of synthetic basestocks provide a great match for the low-temperature needs of snowmobiles and snow blowers where low-temperature stability is important. As a consequence of the inherent design of two-stroke engines, some oil is emitted in the exhaust fumes along with unburned fuel. In environmentally sensitive locations, a biodegradable oil may be required by law or desired by consumer use in chainsaws, snowmobiles, or outboard engines. The readily biodegradability* of Esterex™ NP451** makes it an ideal choice for two-stroke oils for these environmentally sensitive applications.

The esters most commonly used in two-stroke oils are dimerates and polyols. Dimerates exhibit high viscosity and high viscosity indices while retaining excellent low-temperature flow. While dimerates have marginal biodegradability, their lubricity is excellent.

Formulation Data
A typical generic ester-based two-stroke formulation is shown below. The wide range is due to the two different types of two-cycle oils (low ash and ashless) and different quality levels.

Component	Function
Solvent (10 – 20%)	Oil and fuel miscibility, low-temperature flowability
Polyisobutylene (0 – 30%)	Reduced smoke and lubricity
Ester (40 – 85%)	Lubrication and delivery of additive to metal surfaces
Additives (3 – 20%)	Antiwear and detergency control

Selection of a premium additive package will allow the ester-based two-stroke lubricant to meet higher-level performance targets such as those listed below.

- *ISO-L-EGD*
- *JASO FD*
- *ISO-L-EGC*
- *JASO FC*
- *JASO FB*
- *API TC*
- *Husqvarna 242 Chainsaw Test Requirements*
- *Excellent Rotax Snowmobile Engine Test Performance*
- *TISI Requirements for Smoke, Lubricity, and Detergency*
- *NMMA TC-W3™*

*Test method is OECD 301F (28 days) for the neat basestocks; additives can affect the biodegradation of a finished lubricant.

**Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Example of a Synthetic two-stroke TC-W3 (Ashless) oil:

Synthetic Two-Stroke Air-Cooled (Low Ash) Oil: JASO FC/API TC Quality:	
Infineum S911	2.5 to 4.1%
Solvent	25%
Polyisobutylene (PIB)	25%
Ester Basestock	46 to 47.5%

The ester basestocks recommended for this formulation are:

Esterex™ NP451 Thermal and oxidative stability and biodegradable (readily)*
Esterex™ NP343 Thermal and oxidative stability and biodegradable (inherently)*

Additive Requirements

Two-stroke additives are a combination of detergent, dispersant, lubricity, and flow improver components, and may also contain rust and corrosion inhibitors and fuel stabilizers, depending on the type of oil.

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FOUR-STROKE ENGINE

Lubricant Applications
Original Equipment Manufacturers (OEMs) such as Briggs & Stratton and Honda are making increasing use of four-stroke engines to meet tighter emission regulations. Four-stroke engines are used where weight is not a major concern, and are similar in operation to small automobile engines. Unlike two-stroke engines, four-stroke engines have an oil sump from which the oil is recirculated throughout the engine to provide lubrication. The fuel and the oil are not intentionally mixed and are therefore cleaner and friendlier to the environment than that from a traditional two-stroke engine. These small engines are typically used to power motorcycles, generators, outboard engines, personal watercraft, and lawn mowers.

Synthetic oils for these small engines are usually based on PAO/ester and more recently PAO/alkylated naphthalene blends and offer a variety of advantages over mineral oil-based lubricants. The use of PAO in the oil improves both power and performance through dramatic reduction in friction and wear. PAO also provide excellent high-temperature stability for reliable performance and superior oil quality.

Combined with an appropriate additive package, synthetic esters and/or alkylated naphthalenes in combination with PAO fluids may lead to improvements in lubricity and offer excellent antiwear performance in all areas, particularly with respect to high-lift camshafts and other heavily loaded valve train components. The good low-temperature flow characteristics of synthetics can protect the valve gear even in the most severe winter conditions, and also improve cold-start performance.

Lubricant Requirements
As in large engines, synthetic basestocks offer similar advantages in the small four-stroke engines. Synthetic basestocks consist of more-uniform molecular structures than the mixtures of types of molecules in petroleum basestocks. This uniform quality provides benefits for synthetic oils over mineral oils, such as:

- *At higher engine operating temperatures, synthetic oils have been proven to resist high-temperature breakdown and shearing effects for a much longer time period than petroleum oils. This allows the oil to stay in the specified viscosity grade much longer.*

- *Synthetic oils reduce internal friction, providing lower engine operating temperatures as well as smoother shifting.*

- *Synthetic oils will allow a much higher load capacity, as well as provide increased wear protection for critical engine parts such as pistons, cylinders, gears, camshafts, and bearings.*

- *Synthetic basestocks can be used in oils designed for extended drain intervals.*

Formulation Data
The following are representative four-stroke synthetic small-engine formulations using combinations of ExxonMobil Chemical's SpectraSyn™ PAO or SpectraSyn™ PAO/Esterex™ combinations*. ExxonMobil Chemical's alkylated naphthalene Synesstic™ 5 may be substituted for any of the esters to provide greater oxidative and hydrolytic stability. The viscosity modifier used in the 0W-30 formulations must be very shear stable. In the 0W-30 formulations below, the viscosity modifier has an SSI of 10. SpectraSyn™ 40 and 100 are also used as shear stable viscosity modifiers in two of the formulations shown below.

While OEMs have their in-house engine tests, there are two industry specifications for specialty four-stroke engines:

JASO 4T motorcycle specification, T903. Friction performance is the main area of concern, with JASO MA1 and MA2 Classification providing high friction levels Infineum S1857 @ 10.3 to 11.3 wt% can be used for these applications in the formulations below.

National Marine Manufacturer's Association (NMMA) FC-W specification for gasoline fueled marine applications. This specification has a 115HP engine test and requires special additive formulations to meet the FC-W Rust test requirements. Infineum S952 @ 11.0 wt% can be used to meet this specification. Infineum S952 can also meet the high friction requirements of JASO MA1 and MA2 in the motorcycle specification.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

SYNTHETIC FOUR-STROKE SMALL-ENGINE OIL EXAMPLES	0W-30 Weight %	0W-30 Weight %	5W-30 Weight %	10W-30 Weight %	10W-30 Weight %	10W-30 Weight %	10W-40 Weight %
Infineum S1857	10.3	10.3	10.3	10.3	10.3 to 11.5	10.3 to 11.5	10.3 to 11.5
Viscosity Modifier	5.0	7.0	–	–	–	–	4.1
Pour point depressant (if needed for MRV-TP1)	–	–	0.1	0.1	–	–	–
SpectraSyn™ 4	10.0	58.0	–	–	–	–	–
SpectraSyn™ 6	74.7	14.7	80.6	84.6	34.7 to 33.5	80.7 to 79.5	35.7 to 34.5
SpectraSyn™ 8	–	–	–	–	–	9.0	–
SpectraSyn™ 10	–	–	–	–	55.0	–	50.0
Esterex™ P61*	–	10.0	–	–	–	–	–
SpectraSyn™ 40	–	–	9.0	–	–	–	–
SpectraSyn™ 100	–	–	–	5.0	–	–	–

Recommended Basestocks

Esters

Esterex™ NP343*, Esterex™ A51*, Esterex™ P61*

Alkylated Aromatics

Synesstic™ 5

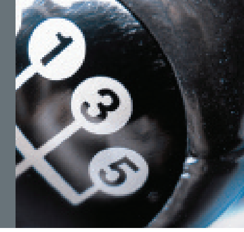
Polyalphaolefins

SpectraSyn™ 4, SpectraSyn™ 6, SpectraSyn™ 8, SpectraSyn™ 10, SpectraSyn™ 40, SpectraSyn™ 100, SpectraSyn Plus™ 3.6, SpectraSyn Plus™ 4, SpectraSyn Plus™ 6

Additive Requirements

Small-engine four-stroke additives are a combination of antiwear, detergent, dispersant, oxidation inhibitor, and rust and corrosion inhibitor components.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.



AUTOMOTIVE GEAR

Lubricant Applications

The automotive vehicles manufactured today have all required gearing of some sort to allow transfer of the engine's power to driving wheels. Generally the gear types are spiral bevel and hypoid. An important feature of gear lubrication is that the contact between the lubricated surfaces is intermittent, permitting them to be flooded with fresh lubricant between contacts. The major function of gear lubricants, transmission or axle oils, is to provide protection to the moving and mating parts. The parts include manual transmissions, drive axles (differentials), and power takeoffs, and nondrive applications (steering, trailer axles, rear axles in front-wheel-drive vehicles).

A number of advantages may be associated with the use of synthetic lubricating oils in automotive gears, including the following:

- *Better low-temperature properties*
- *Improved viscometrics at high temperature (high VI)*
- *Improved thermal and oxidative stability*
- *Lower volatility*
- *Improved solubility characteristics*
- *High efficiency*

In automotive gears, the following application-related advantages should result from synthetic oils as compared to mineral oils:

- *Extended service life, up to 15 times the standard drain interval*
- *Cleaner equipment, less varnish and sludge*
- *Extended bearing life*
- *Improved seal life*
- *Lower repair maintenance*
- *Improved fuel efficiency*
- *Less in-shop downtime*
- *Less oil disposal*

Synthetic basestocks can be used to formulate broad multigrade lubricants such as 75W-90 or 80W-140. Lubricants in these viscosity grades are generally suitable for a wide range of operating temperatures in automotive gears.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Lubricant Requirements

The two main types of synthetic gear oil are PAO-based and PAO/ester-based. A properly formulated PAO gear oil will show improvement in low-temperature performance, high-temperature bulk viscosity, and thermal and oxidative stability.

The ester-containing synthetic gear lubes show better miscibility with most additive systems. The addition of ester (diester, polyol ester, or mixture) to PAO can improve additive solubility and increase the polarity of the entire basestock system, which moderates the normal shrinking and hardening tendencies of elastomer seals.

PAO and ester basestocks show significantly lower pour points than comparable petroleum oil due to a tailored molecular structure and the absence of wax, which is typically found in mineral oils. The low pour point of the synthetic basestocks allows the formulator to secure improved low-temperature properties in gear oils.

Synthetic automotive gear lubricants (PAO and ester) show improved resistance to thermal and oxidative degradation compared to petroleum basestocks. Of the basestocks currently used in automotive gear lubricants, polyol esters are the most thermally stable, followed by diesters and PAO.

Use of PAO continues to grow in heavy duty gear oil applications and shows promise as a means to extend drains in heavy duty diesel engines.

Recommended Basestocks

These basestock formulations provide guidelines to developing various synthetic gear oil grades based on ExxonMobil Chemical's SpectraSyn™ PAO and Esterex™ esters*. Both formulations meet the requirements of SAE J2360.

Formulation Data

SAE J2360 APPROVED SAE 75W-90 AND 75W-140 GEAR OILS

	Mass % 75W-90	Mass % 75W-140
Gear Oil Additive Pkg.	6.00	6.00
SpectraSyn™ 4	–	16.94
SpectraSyn™ 6	75.83	–
SpectraSyn™ 100	–	57.04
Infineum C9925	18.13	–
Esterex™ A32*	–	20.00
Defoamant	0.04	0.02

Typical Inspection Properties:

PROPERTY	METHOD	75W-90	75W-140	SAE J2360 SPECIFICATION
Viscosity @ 40°C, cSt	D 445	132.1	177.5	–
Viscosity @ 100°C, cSt	D 445	17.7	–	13.5 - 24.0
Viscosity @ 100°C, cSt	D 445	–	24.75	24.0 - 41.0
Viscosity @ -40°C, cP	D 2983	93,800	120,200	150,000 max
Viscosity Index	D 2270	149	172	–
API Gravity, degrees	D 287	35.1	31.5	–
Flash Point, °C	D 92	210	210	–
Pour Point, °C	D 97	-60	-48	–
Channel Point, °C	FTM 3456	<-45	<-45	<-45
Copper Corrosion, 3h @ 121°C	D 130	1b	1b	2a max
Foaming Tendency	D 892	–	–	–
	Seq. I, mL @ 24°C	0	0	20 max
	Seq. II, mL @ 93°C	0	0	50 max
	Seq. III, mL @ 24°C	0	0	20 max
Storage Stability & Compatibility	FTM 3430/3440	Pass	Pass	Pass

Note: cSt=mm^2/s; cP=mPa-s

A potential upgrade to this formulation would include the use of ExxonMobil Chemical's Synesstic™ 5 in place of Esterex™ A32* for added hydrolytic stability as well as additive solubility. Because of its lower VI, its effect on the low-temperature performance should be checked to assure adequate Brookfield viscosity performance.

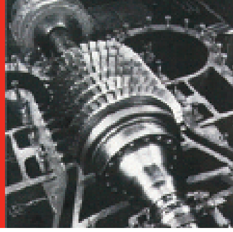
Another suggested upgrade would be the use of ExxonMobil Chemical's SpectraSyn Ultra™ in place of some of the Infineum C9925 for added wear protection.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.
** = Not always required. Application dependent.

Additive Requirements

Finished gear lubricants typically are composed of high-quality basestocks with between 5 and 10% additive, depending on desired performance characteristics. These additives include:

*Antiwear***
*Oxidation Inhibitor***
Extreme Pressure
Dispersant
Rust Inhibitor
Corrosion Passivator
*Friction Modifier***
*Polymer***



GAS COMPRESSOR LUBRICANTS

Lubricant Applications

The air compressor is an integral part of a facility's air system. The air system is responsible for the collection, compression, cooling, filtration, and delivery of air to the functioning equipment. A large variety of compressor types is available, but the most severe operation is observed with rotary compressors (screw and sliding vane) and reciprocating compressors (water-cooled and air-cooled). The high temperatures of operation (250°F to 500°F) require drain intervals with mineral oil to be in the region of 500 to 1000 hours. Use of the synthetic fluids increases drain intervals up to 8000 hours for rotary compressors, and provides long-life discharge valve cleanliness in reciprocating compressors. The higher cost of the synthetic lubricant can be readily justified by the increased drain interval, reduced maintenance, and reduced equipment downtime.

In general, both PAO- and diester-based lubricants are recommended for use in both rotary and reciprocating compressors. ISO VG 32, 46, and 68 are the recommended viscosity grades for rotary compressors, with ISO VG 100 and 150 recommended for reciprocating compressors.

Lubricant Requirements

Ester-Based Compressor Lubricants

Ester-based compressor lubricants contain appropriate additives to provide premium performance. Their polar characteristics lead to excellent cleanliness in air-compressor lubrication.

In rotary applications, ester-based lubricants provide natural detergency and do not form insoluble varnishes or heavy polymers. They have excellent oxidative and thermal stability and also provide excellent lubricity and wear protection. As a result, they provide extended oil, filter, and air-oil separator life beyond that of conventional mineral oil-derived lubricants.

In reciprocating compressor applications, the lubricants are used where there are high discharge temperatures. The low carbon-forming tendencies of these lubricants may reduce or eliminate deposit formation on the discharge valves, leading to safer operation (removes ignition source for fires) as well as extending ring, cylinder, and valve life and keeping intercoolers, aftercoolers, and piping clean.

PAO-Based Compressor Lubricants

All PAO-derived synthetic air compressor lubricants must contain appropriate additives to provide premium performance, and generally require an ester to improve additive solubility and seal compatibility.

In rotary applications, PAO-based lubricants provide superior thermal and oxidative stability over a wide range of temperatures as well as improved water tolerance and protection against corrosion. They are particularly effective in rotary compressors having oil-injection cooling with high final compression temperatures, or in compressors that tend to form varnish and other system deposits. Drain intervals are significantly increased over mineral oils and may also have longer drain intervals than ester-based lubricants. The excellent hydrolytic stability of the PAO-based lubricants is especially important in humid environments.

In reciprocating compressor applications, the lubricants are used where there are high discharge temperatures. With the proper selection of PAO, the lubricant can have low volatility and low carbon-forming tendencies, which result in clean compressor operating conditions. Another benefit of PAO-based lubricants is their compatibility with elastomers and paints found in older machines that were designed for use with mineral oils. Use of alkylated naphthalene in combination with the PAO should result in greater oxidative and thermal stability.

In all applications, these lubricants have a broad operating temperature range with good low-temperature properties. Use of the polyol esters should result in greater oxidative and thermal stability.

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Formulation Data (Weight %)

Diester/Trimellitate-Based

The following basestock ratios are recommended for the formulation of the various viscosity grades of ester-based compressor lubes. These ratios were blended with appropriate additive components, and the physical properties of the blends are shown below. These blends can serve as a guideline for ester-based compressor oil formulation.

ISO VG	32	46	68	100
Esterex™ A51*	83.9	53.3	19.7	–
Esterex™ P81*	14.8	45.4	79.0	62.2
Esterex™ TM111*	–	–	–	36.5
Additive Package**	1.30	1.30	1.30	1.30
PROPERTIES	**32**	**46**	**68**	**100**
KV @ 100°C, cSt	5.7	6.6	7.8	9.8
KV @ 40°C, cSt	32.7	47.5	70.8	103.2
Viscosity Index	105	76	48	62
SG 15.6/15.6°C	0.926	0.941	0.954	0.970
Flash Point, °C, Open Cup	252	270	272	–
Fire Point, °C	288	–	296	–
Pour Point, °C	-45	-42	-39	-33
Demulsibility – (82.2°C) Oil/Water/Cuff (min)	38/40/2 (25)	41/39/0 (15)	41/34/0 (10)	40/40/0 (5)

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

**Combination of dioctyldiphenylamine, benzotriazole, phenyl alpha-naphthylamine.

Additive Requirements

Other typical ester compressor oil formulations would contain a total of 1% to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Antiwear
Antifoamant
Corrosion Inhibitor
Demulsifier
*Dispersant****
Extreme Pressure
*Friction Modifier****
Oxidation Inhibitor
Rust Inhibitor

*** = Not always required. Application dependent.

Formulation Data (Weight %)

PAO/Ester-Based

ISO VG	32	46	68	100	150
SpectraSyn™ 6	84	74	63	53	42
SpectraSyn™ 100	1	11	22	32	43
Esterex™ A51*	15	15	15	15	15
PROPERTIES	**32**	**46**	**68**	**100**	**150**
KV @ 100°C, cSt	5.9	7.9	11.1	15.0	21.0
KV @ 40°C, cSt	30.5	44.1	67.3	99.0	151.2
Viscosity Index	140	153	158	159	163
SG 15.6/15.6°C	0.833	0.841	0.844	0.847	0.850
Flash Point, °C, Open Cup	236	241	243	253	253
Fire Point, °C	269	273	277	277	281
Pour Point, °C	-58	-56	-54	-51	-48

Use of alkylated naphthalene as the blendstock will result in increased thermal, oxidative, and hydrolytic stability.**

PAO/Alkylated Naphthalene-Based

ISO VG	32	46	68	100	150
SpectraSyn™ 6	84	74	63	53	42
SpectraSyn™ 100	1	11	22	32	43
Synesstic™ 5	15	15	15	15	15
PROPERTIES	**32**	**46**	**68**	**100**	**150**
KV @ 100°C, cSt	5.7	7.9	11.1	15.1	20.8
KV @ 40°C, cSt	30.4	45.3	69.9	103.5	156.2
Viscosity Index	132	145	150	153	156
SG 15.6/15.6°C	0.834	0.840	0.842	0.846	0.846
Flash Point, °C, Open Cup	234	236	236	239	240
Fire Point, °C	270	268	270	271	268
Pour Point, °C	-60	-57	-51	-45	-39

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

**Based on the comparative results of ASTM tests D 2272, D 943, and D 2619.

Additive Requirements

A typical PAO-based compressor oil formulation would contain a total of 0.5 to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Antiwear	*Rust Inhibitor*
Oxidation Inhibitor	*Antifoamant*
Corrosion Passivator	*Demulsifier*
*Dispersant****	

*** = Not always required. Application dependent.

REFRIGERATION COMPRESSOR

Lubricant Applications

The refrigeration compressor is an integral part of the refrigeration system. The compressor is responsible for drawing in the refrigerant gas, compressing the gas, and thereby raising its temperature and boiling point. Refrigeration lubricants must act as an oil sealant between the compression and suction actions of the reciprocating compressors, form a seal in rotary-type compressors, serve as a coolant to remove heat from the compressor, and lubricate internal parts.

Lubricant Requirements

The PAO-based lubricants offer significant advantages versus mineral oil-based lubricants in that they have no wax content and offer very low pour points. They have a very high viscosity index. Because of these properties, the PAO-based lubricants offer better protection against wear of bearings, cylinders, and piston rings. In addition, PAO fluids are ideal for use with carbon dioxide and hydrocarbon refrigerant gases.

In rotary screw compressors where the sealing effect of the lubricant is important to overall efficiency, these lubricants may potentially offer benefits in volumetric efficiency. They are also stable in the presence of refrigerants at the temperatures and pressures found in the refrigeration systems.

Since they are chemically similar to mineral oils, they are usually compatible with the same type of seals and coatings as mineral oils.

Formulation Data (Weight %)
PAO-Based

	VG 5	VG 7	VG 10	VG 15	VG 22	VG 32
SpectraSyn™ 2	100	72	44	18	–	–
SpectraSyn™ 4	–	28	56	82	70	–
SpectraSyn™ 6	–	–	–	–	30	100

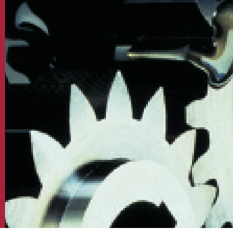
	VG 46	VG 68	VG 100	VG 150	VG 220
SpectraSyn™ 6	–	–	54	38	23
SpectraSyn™ 8	100	–	–	–	–
SpectraSyn™ 10	–	100	–	–	–
SpectraSyn™ 40	–	–	46	62	77

Additive Requirements

Typical PAO refrigeration lubricants may contain 0.1 to 2.0% of the following additives, with the remainder, depending on the viscosity grade, being the above basestocks.

Antiwear
Oxidation Inhibitor

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.



Lubricant Applications

Lubricants for gearing systems are required to transfer forces, minimize wear, reduce friction, dissipate heat, and remove abrasive particles. Synthetic gear oils are typically used whenever mineral gear oils have reached their performance limits and can no longer meet the application requirements. Examples are: very low or high temperatures, extremely high loads, extraordinary ambient conditions, or failure to meet special requirements such as flammability.

Synthetic oils provide a number of advantages in gearing systems. The advantages of synthetic lubricating oils may include:

- *Improved thermal and oxidation resistance*
- *Improved viscosity-temperature behavior, high viscosity index (in most cases)*
- *Improved low-temperature properties*
- *Lower evaporation losses*
- *Reduced flammability*
- *Improved lubricity*
- *Lower tendency to form residues*

In gearing systems, the following application-related advantages should result from the improved properties of synthetic lubricating oils as compared to mineral oils:

- *Improved efficiency due to reduced tooth-related friction losses*
- *Lower gearing losses due to reduced friction, requiring less energy*

- *Oil change intervals three to five times longer than mineral oils operating at the same temperature*
- *Reduced operating temperatures under full load, increasing component life; cooling systems may not be required*

Lubricant Requirements

PAO-based synthetic lubricants are used for industrial gear lubrication. Esters (diesters) are formulated with the PAO to provide additive solubility, improved seal compatibility, and sludge control. For additional potential performance benefits such as improved overall wear protection, conventional PAO in conjunction with HVI PAO can be used. The severity of application will usually drive the selection of PAO grade and finished oil viscosity.

Recommended Basestocks (Weight %)
PAO/Diester-Based

	VG 100	VG 150	VG 220	VG 320	VG 460	VG 680
SpectraSyn™ 6	53	42	31	21	11	1
SpectraSyn™ 100	32	43	54	64	74	84
Esterex™ A51*	15	15	15	15	15	15

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Additive Requirements

A synthetic gear-oil formulation can contain a total of 1 to 5% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

*Antiwear***	*Dispersant***
Antifoamant	*Extreme Pressure*
Corrosion Passivator	*Friction Modifier***
Demulsifier	*Oxidation Inhibitor*
*Detergent***	*Rust Inhibitor*

** = Not always required. Application dependent.

The following ISO VG 220 formulation meets all of the requirements of USS 224 and AGMA 9005-D94. This formulation also meets Cincinnati Milacron P-74, David Brown, and DIN 51 517 Part 3 (1989) specifications.

VG 220 INDUSTRIAL GEAR	
SpectraSyn™ 6	30%
SpectraSyn™ 100	53.5%
Esterex™ A51*	15%
Gear Oil Additive Package	1.5%

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

USS 224 & AGMA 9005-D94 PERFORMANCE IN ISO VG 220 SYNTHETIC INDUSTRIAL GEAR OIL

TEST 1	METHOD	REQUIREMENTS FOR AIST 224	REQUIREMENTS FOR AGMA 9005-D94	RESULTS
API GRAVITY, Degrees	D 287	25 min		**34.1**
KINEMATIC VISCOSITY	D 445			
@ 40°C, cSt		198-242	198-242	**224.0**
@ 100°C, cSt		Report	Report	**27.9**
VISCOSITY INDEX	D 2270	95 min	120 min	**162**
PRECIPITATION NO.	D 91	Trace		**Nil**
POUR POINT, °F	D 97	15 max	-22 max	**-52**
FLASH POINT, °F	D 92	450 min		**455**
COPPER CORROSION	D 130	1B max	1B max	**1A**
FOAM	D 892			
Sequence I			75/10	**0/0**
Sequence II			75/10	**70/0**
Sequence III			75/10	**20/0**
STEEL CORROSION	D 665			
Part A		Pass		**Pass**
Part B		Pass	Pass	**Pass**
OXIDATION	USS S-200			
Visc. Increase, %		6.0 max	6.0 max	**1.46**
Precipitation No., %		0.1 max	0.1 max	**Trace**
4-BALL EP	D 2783			
Load Wear Index, kg		45 min		**53.8**
Weld Point, kg		250 min		**250**
4-BALL WEAR	USS S-205			
Scar Diameter, mm		0.35 max		**0.28**
DEMULSIBILITY	D 2711			
Free water, ml		80.0 min	60.0 min	**87.0**
Emulsion, ml		1.0 max	1.0 max	**Trace**
Water in oil, %		2.0 max	2.0 max	**0.05**
TIMKEN – OK LOAD, lb	D 2782	60 min		**90+**
FZG GEAR TEST	USS S-70[2]	12 min	10 min	**>12**

1 Tests run at UEC Lube Labs, Monroeville, PA.
2 The AGMA specification calls for the FZG Gear Test to be run via DIN 51 354. The test conditions are less severe than US Steel's S-70; therefore, this oil should readily meet the AGMA requirement.

Source: ExxonMobil Data

Suggested upgrades to this formulation would include the use of SpectraSyn Ultra™ in place of some of the SpectraSyn™ 100 for added wear protection.

HYDRAULIC SYSTEM

Lubricant Applications

Hydraulic systems are utilized to transmit and apply large forces while retaining flexibility and control. Such a system transmits, transforms, and controls mechanical work. A typical hydraulic system, besides the fluid, includes:

- *A force-generating unit that converts mechanical energy into hydraulic energy, such as a pump*
- *Piping for transmitting fluid under pressure*
- *A unit that converts the hydraulic energy of the fluid into mechanical work, such as an actuator or fluid motor*
- *A control circuit with valves that regulate flow, pressure, direction of movement, and applied forces*
- *A fluid reservoir that allows for separation of any water or debris before the fluid is returned to the system through a filter*

The pump can be considered the heart of the system, and the hydraulic fluid the lifeblood of the equipment. Good wear control by the fluid is essential for pump efficiency. Wear causes internal slippage or leakage, which reduces the pump output, resulting in power loss and increased operating temperatures.

Lubricant Requirements

In general, both PAO and ester-based lubricants can be utilized to formulate hydraulic fluids. All synthetic hydraulic fluids need appropriate additives to provide premium performance. The PAO-based products typically require an ester to improve additive solubility and seal compatibility.

Excellent wear control is essential in a hydraulic fluid. The formulated lubricant must also resist compression and flow readily at all operating temperatures. It must also provide adequate seal compatibility, be corrosion resistant, and separate readily from water and debris while in the sump before being recirculated.

Synthetic hydraulic fluids based on PAO and/or esters may be more durable under thermal and oxidative stress, are cleaner in operation, and are able to span wider areas of use. Synthetic fluids may be justified despite their higher initial cost when used in severe oxidative or high-temperature environments by increasing the lube life.

When properly formulated with antiwear-containing hydraulic fluid additive packages, PAO and polyol ester combinations are recommended for systems using gear, piston, or vane pumps operating at either high or low pressures. The high VI and wax-free composition of such lubricants provide a wide operating temperature range. Such fluids should meet the requirements of Denison HFO, Vickers V-104C and 35VQ25, and Sundstrand pumps.

The basestock formulations below demonstrate the flexibility to blend various viscosity grades of hydraulic fluids. The use of HVI PAO should provide some additional wear protection. The polyol ester/PAO and the all-polyol ester formulations both should benefit from the higher oxidative and thermal stability of the polyol esters.

Basestock Formulations (Weight %)

ISO VG	15	32	46	68
SpectraSyn™ 2	16.7	–	–	–
SpectraSyn™ 4	67.0	–	–	–
SpectraSyn™ 6	–	80.8	70.9	59.1
SpectraSyn™ 100	–	2.9	12.8	24.6
Esterex™ NP343*	14.8	14.8	14.8	14.8
Additive**	1.5	1.5	1.5	1.5
PROPERTIES	**15**	**32**	**46**	**68**
KV @ 100°C, cSt	3.4	5.8	8.1	11.3
KV @ 40°C, cSt	13.9	30.6	44.8	64.99
Viscosity Index	121	133	156	168
SG 15.6/15.6°C	0.832	0.844	0.846	0.848
Flash Point, °C, Open Cup	170	208	180	214
Fire Point, °C	192	280	276	276
Pour Point, °C	-57	-48	-48	-45
Demulsibility – (82.2°C) Oil/Water/Cuff (min)	40/40/0 (3)	40/40/0 (3)	40/40/0 (5)	40/40/0 (6)

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

**Additive RC9303 (corrosion inhibitor and antioxidant).

Suggested upgrades to this formulation would include the use of Synesstic™ 5 in place of Esterex™ NP343* for added hydrolytic stability as well as additive solubility and SpectraSyn Ultra™ in place of some of the SpectraSyn™ 100 for added wear protection.

Additive Requirements

A typical hydraulic fluid formulation would contain a total of 0.5 to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Antiwear	*Extreme Pressure***
Antifoamant	*Friction Modifier***
Corrosion Inhibitor	*Oxidation Inhibitor*
Demulsifier	*Rust Inhibitor*

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

** = Sometimes

INDUSTRIAL OVEN CHAIN

Lubricant Applications

Industrial chains often work under severe conditions of heat. Large chains are mainly used in conveyor systems, and can be found in many industries such as textile (stentor chains), in car factories, pottery and glass kilns, plastic film, fiberglass insulation, and in ovens used in food processing. The most challenging lubrication applications are mainly those involving severe heat from ovens (e.g., high-temperature conveyor bearings). Synthetic lubricants in severe heat situations need to be able to handle conditions as high as 260°C.

Lubricant Requirements

PAO and/or ester-based synthetic fluids can be effectively used for industrial chain lubrication in “hot” applications. Typically, these synthetic fluids are formulated with polybutene (thickener) and additives. The additives can be ashless or ash-containing (generally some combination of the two). Esters that can be used for “hot” applications include adipates and trimellitates in combination with polyalphaolefins, which provide a more stable alternative to polybutenes. Use of the polyol esters should lead to improved oxidative and thermal stability.

Basestock Formulations (Weight %)

	VG 68	VG 150	VG 150	VG 220	VG 220
Esterex™ TM111*	–	87	–	52	–
Esterex™ NP343*	69	–	50	–	41
SpectraSyn™ 40	–	13	–	48	–
SpectraSyn™ 100	31	–	50	–	59

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Additive Requirements

A synthetic oven chain oil formulation would contain a total of 0.5 to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Extreme Pressure	*Antiwear*
Oxidation Inhibitor	*Detergent*
Corrosion Passivator	*Friction Modifier***
Antifoamant	

** = Not always required. Application dependent.

MIST SYSTEM

Lubricant Applications

An oil mist system is a centralized lubrication system that generates, conveys, and automatically delivers lubricant. It has no moving parts. The heart of an oil mist system is the generator, which utilizes the energy of compressed air to atomize oil into micron-sized particles. The lean mixture of oil and air produced by the generator is known as oil mist and has the consistency of cigarette smoke. The oil particles form a stable suspension that can be conveyed considerable distances through piping and tubing directly to the point requiring lubrication. When it reaches the target part, it is reclassified into larger droplets before plating out on the machinery part to be lubricated. Oil mist lubrication is used on pumps, electric motors, steam turbines, gear boxes, and blowers. This closed system of lubrication is very clean and provides several advantages:

- *Reduced bearing failures (up to 90%)*
- *Cooler running/energy conserved*
- *More efficient lubrication*
- *Reduced lubricant consumption*
- *Contaminants excluded*

Lubricant Requirements

In general, both PAO-and ester-based lubricants can be utilized for mist lubrication. All synthetic mist lubricants must contain appropriate additives to provide premium performance. The formulated lubricant must provide wear protection against heavy loads, have good surface-wetting characteristics, and must be able to be readily misted. These lubes must also be formulated to be virtually free of stray mist when used in properly designed and adjusted systems. They should also have good EP properties and oxidation stability. The higher-viscosity grades (ISO VG 220 and higher) are typically utilized for heavily loaded bearings, and the lower-viscosity grades are used for bearings, gears, screws, and metallic ways.

The use of esters and PAO in this application provides greater stability for the lubricant, and the HVI PAO component may assist in the reduction of stray mist.

Basestock Formulations (Weight %)

Ester/HVI PAO-Based

	VG 32	VG 46	VG 68	VG 100	VG 150	VG220	VG 320	VG 460
Esterex™ A51*	96	89	84	78	71	64	58	52
SpectraSyn Ultra™ 300	4	11	–	–	–	–	–	–
SpectraSyn Ultra™ 1000	–	–	16	22	29	36	42	48

PAO/HVI PAO/Polyol Ester-Based

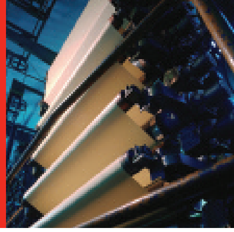
	VG 32	VG 46	VG 68	VG 100	VG 150	VG220	VG 320	VG 460
SpectraSyn™ 6	83	75	70	63	56	50	43	37
SpectraSyn Ultra™ 300	2	10	–	–	–	–	–	–
SpectraSyn Ultra™ 1000	–	–	15	22	29	35	42	48
Esterex™ NP343*	15	15	15	15	15	15	15	15

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Additive Requirements

A typical mist oil formulation would contain a total of 0.5 to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Antiwear	*Rust Inhibitor*
Extreme Pressure	*Antifoamant*
Corrosion Passivator	*Demulsifier*
Oxidation Inhibitor	



PAPER MACHINE

Lubricant Applications

Synthetic lubricants used in paper machines are intended primarily for the lubrication of plain bearings, roller bearings, and parallel shaft gearing. Applications include splash, bath, and ring oil arrangements and all other methods involving pumps, valves, and auxiliary equipment. The synthetic lube is particularly effective in the circulating systems of paper machines, where it performs well at high operating temperatures normally found in the dryer sections of paper machines. The lube must be particularly resistant to contamination by water, acidic solutions, and process chemicals normally encountered in paper machine systems.

Lubricant Requirements

Paper machine lubricants are premium lubricants formulated to perform dependably under the hot, wet degradation conditions of paper machine operation. The oil must have outstanding resistance to oxidation and thermal decomposition, potent detergency to prevent deposit buildup on hot surfaces, and excellent demulsibility and rust protection. It also must be readily filterable through filters with porosity as fine as six microns. These features, derived from a careful blending of additives and high-quality synthetic basestocks, are essential to extending equipment life and reducing costly unscheduled downtime. Combinations of PAO and alkylated naphthalene or esters for additive solubility can be used in combination with the appropriate additives. The alkylated naphthalene provides hydrolytic stability when used in place of an ester.

Recommended Basestocks

PAO/Alkylated Naphthalene

	VG 150	VG220	VG 320	VG 460
SpectraSyn™ 6	37	25	16	6
SpectraSyn™ 100	43	55	64	74
Synesstic™ 5	20	20	20	20

Additive Requirements

A typical paper machine lubricant formulation could contain a total of 0.5 to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

*Extreme Pressure**	*Antiwear*
Oxidation Inhibitor	*Antifoamant*
Demulsifier	*Dispersant**
Rust Inhibitor	*Friction Modifier*

* = Not always required. Application dependent.

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

GREASE

Lubricant Applications

A grease is a lubricant of fluid-to-firm consistency produced by the thickening of a liquid lubricant (mineral oil or synthetic fluid) with a stable, homogeneous dispersion of a solid-phase thickener and containing such additives as required to impart special characteristics.

Greases are used in the temperature range from -70°C to 350°C and are used to lubricate machine elements such as antifriction and plain bearings, gears, slideways for launching of ships, joints, etc. Greases can also act as sealants. Due to their versatile properties, they are used in practically all areas of industry to solve lubrication problems which cannot be solved by the use of lubricating oils for economic or technical reasons.

Lubricant Requirements

There are numerous applications for synthetic grease, and the end use determines the type of synthetic basestock to be employed. Greases based on synthetic basestocks such as PAO or PAO/alkylated naphthalene or PAO/ester combinations can be designed for a wide variety of end-use applications at temperature extremes. They combine the unique features of a synthetic basestock with those of a high-quality thickener. The wax-free nature of the synthetic basestock and the low coefficient of traction (PAO compared with mineral oils) provide excellent low-temperature pumpability and very low starting and running torque. Such products offer the potential for energy savings and can reduce operating temperatures in the load zone of rolling element bearings. Use of a lithium complex thickener contributes excellent adhesion, structural stability, and resistance to water. The greases have a high level of chemical stability and can be formulated with special additive combinations to provide excellent protection against wear, rust, and corrosion at high and low temperatures. Because of the broad range of viscosities, synthetic greases can be prepared in several viscosity grades ranging from ISO VG 100 to 1500 and in NLGI grade from 2 to 00.

These greases can be used in a wide range of applications and a broad range of operating temperatures, depending on grade. They are not only used in numerous industrial applications, but also find significant usage in automotive, marine, and aerospace sectors.

Synthetic greases have become the products of choice for many users in many industries worldwide. Their reputation is based on their exceptional quality, reliability, and versatility and the performance benefits they deliver. Some of the specific features and benefits resulting from the use of synthetic greases are shown below.

FEATURE	ADVANTAGE AND POTENTIAL BENEFITS
Outstanding high-temperature and low-temperature performance	Wide application temperature ranges, with excellent protection at high temperatures and low torque, easy start-up at low temperatures
Excellent protection against wear, rust, and corrosion	Reduced downtime and maintenance costs because of reduced wear, rust, and corrosion
Excellent thermal stability and oxidation resistance	Extended service life with longer intervals between relubrication and improved bearing life
Low traction coefficient	Potential improved mechanical life and reduced energy consumption
Includes high viscosity grades with high VI, no wax basestocks	Outstanding protection of slow speed, heavily loaded bearings with good low-temperature performance
Outstanding structural stability in the presence of water	Retains excellent grease performance in hostile aqueous environments
Low volatility	Helps resist viscosity increase at high temperatures to maximize relubrication intervals and bearing life

Formulation Data

A typical simplified synthetic grease formulation is shown below. In reality, considerable formulation science is required to achieve all of the performance features of premium greases.

Synthetic Basestock	75 – 95%
Thickener	5 – 20%
Additives	0 – 15%

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Recommended Group IV Synthetic Basestocks

Polyalphaolefins: Alone or in combination with an ester or alkylated naphthalene, the PAO fluids lubricate over a broad temperature range (-37°C to 200°C), offer lubrication protection for components operating under severe conditions, and offer energy efficiency features. Additionally they are available in a broad viscosity range, are compatible with mineral oils, have been used in greases for 40 years, and are compatible with elastomers, paint, and plastic.

Polyalphaolefins

SpectraSyn™ 4 – 100
SpectraSyn Plus™ 3.6 – 6
SpectraSyn Ultra™ 150 – 1000

Recommended Group V Synthetic Basestocks

Alkylated Naphthalene: When used in combination with PAO, the resulting grease has good low-temperature dispensability, high-temperature adhesive properties, and rust-inhibiting properties. Additionally, use of AN reduces the amount of thickener required, aids additive solubility by their increased polarity, and provides hydrolytic stability.

Diester and polyol esters: Suitable for use in low- and high-temperature applications (-37°C to over 177°C) and also where biodegradability may be required. In combination with PAO they aid additive solubility by providing increased polarity. The polyol esters provide greater oxidative and thermal stability than diesters.

Esters

Esterex™ A32*, Esterex™ A51*, Esterex™ NP451*

Alkylated Aromatics

Synesstic™ 5, Synesstic™ 12

Additive Requirements

A typical grease formulation could contain up to 15% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Antiwear
Oxidation Inhibitor
*Extreme Pressure***
*Polymer***
Rust Inhibitor
*Corrosion Passivator***
*Friction Modifier***

Basestock Formulations (Weight %)

The formulations below represent recommended blend ratios to achieve the basestock viscosity of the various grades of grease. In vegetable oil-derived biodegradable greases, Esterex™ esters* can be added to improve the low-temperature performance as well as the oxidative stability.

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.
** = Not always required. Application dependent.

	VG 15	VG 100	VG 220	VG 460	VG 1500
SpectraSyn™ 4	100	–	–	–	–
SpectraSyn™ 6	–	54	23	27	16
SpectraSyn™ 40	–	46	77	–	–
SpectraSyn™ 100	–	–	–	73	–
SpectraSyn Ultra™ 300	–	–	–	–	84

TYPICAL PROPERTIES OF SPECTRASYN™ PAO-DERIVED GREASE

	100	220	460	1500
NLGI Grade	2	2	1.5	1
Thickener Type	Lithium complex	Lithium complex	Lithium complex	Lithium complex
Penetration, Worked, 25°C, ASTM D 217	280	280	305	325
Dropping Point, °C, ASTM D 2265	255	255	255	255
Viscosity of Oil, ASTM D 445, cSt @ 40°C	100	220	460	1370
Timken OK Load, ASTM D 2509, lb.	–	50	70	–
4-Ball Weld, ASTM D 2596, Load, kg	250	250	250	250
Water Spray Off, ASTM D 4049, weight loss	–	45	35	25
Water Washout, ASTM D 1264, Loss at 79°C. % weight	6	4	–	–
Rust Protection, ASTM D 6138	–	–	0,0	–
Corrosion Protection, ASTM D 1743, Rating	Pass	Pass	Pass	Pass
US Steel Mobility @ -18°C	–	6	5	4

Source: ExxonMobil Data

TURBINE

Lubricant Applications

A turbine is a device that converts the force of a gas or liquid moving across a set of rotor and fixed blades. There are three basic types of turbines: gas, steam, and hydraulic.

Gas turbines are powered by the expansion of compressed gases generated by the combustion of a fuel. Some of the power thus produced is used to drive an air compressor, which provides the air necessary for combustion of the fuel. In other applications, however, the rotor shaft provides the driving thrust to some other mechanism, such as a generator. Thus, gas turbines power locomotives, ships, compressors, and small to medium-sized electric utility generators.

Steam turbines employ steam that enters the turbine at high temperature and pressure, and expands across both rotating and fixed blades (the latter serving to direct the steam). Steam turbines, which power large electric generators, produce most of the world's electricity. Only high-quality lubricants are able to withstand the wet conditions and very moderate temperatures associated with steam turbine operation. The term *turbine oil* has thus become synonymous with quality.

Hydraulic turbines (water turbines or hydro turbines) are either impulse type, in which falling water hits blades or buckets on the periphery of a wheel that turns a shaft, or reaction type, where water under pressure emerges from nozzles on the wheel, causing it to turn. Hydraulic turbines can be used to produce electric power near reservoirs or river dams.

Lubricant Requirements

Combinations of polyalphaolefins, when formulated with or without sufficiently hydrolytically stable esters and appropriate additives, can meet the requirements of both gas and steam turbine lubrication.

In gas turbines, the properly formulated PAO and ester lubricants can provide superior rust protection, low-temperature fluidity, and high-temperature oxidation stability. They can be used as circulating oils for the lubrication of land-based gas turbines, particularly units under 3000 hp used as standby power units, and in some types of total energy systems.

In steam turbines, the properly formulated PAO and ester lubricants can provide exceptional chemical stability, outstanding resistance to oxidation, superior demulsibility, and protection against rust and deposits. These lubricants can also survive hydrolytic attack under the wet conditions in a steam turbine. Among their applications would be use in the circulation systems of direct-connected steam turbines and ring-oiled bearings of geared or direct-connected turbines. Ester selection is key to the critical feature of hydrolytic stability.

Formulation Data

Recommended Basestocks

PAO/DIESTER-BASED			
	VG 32	VG 46	VG 68
SpectraSyn™ 6	83	69	53
SpectraSyn™ 40	2	16	32
Esterex™ A51*	15	15	15

PAO/HIVI PAO/POLYOL ESTER-BASED			
	VG 32	VG 46	VG 68
SpectraSyn™ 6	83	75	66
SpectraSyn Ultra™ 300	2	10	19
Esterex™ NP343*	15	15	15

*Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

Additive Requirements

A typical turbine oil formulation could contain a total of 0.5 to 6% of the following additives, with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

*Extreme Pressure***
Rust Inhibitor
Oxidation Inhibitor
Corrosion Passivator
*Friction Modifier***
Antiwear
*Dispersant***
Antifoamant
Demulsifier

** = Not always required. Application dependent.

Lubricant Application

Heat transfer fluids are designed for use in circulating liquid phase heating and cooling systems. They provide a circulating medium that absorbs heat in one part of a system (e.g., a solar heating system or a remote oil-fired system) and releases it to another part of the system. Heat transfer fluids should meet the operating needs of virtually any single or multiple station heat-using system. In properly designed systems, heat transfer fluids will perform within their respective temperature ranges for extended periods without breakdown or corrosion. Heat transfer fluids require high resistance to cracking (molecular breakdown) when used at temperatures above 260°C (500°F). Available in various types and operating ranges, these fluids provide benefits – economy, efficient operation, minimum maintenance and precise temperature control.

Systems can be either closed or open to the atmosphere. To prevent oxidation in a closed system an inert gas is sometimes used in the expansion tank (or reservoir) to exclude air (oxygen). If the system is open and the fluid is exposed simultaneously to air and to temperatures above 66°C (150°F), the fluid must also have good oxidation stability, since a protective gas blanket cannot be contained.

About 45% of the heat transfer fluids are mineral oils. The main synthetic fluids are polyglycols, silicones and specialized hydrocarbons such as hydrogenated polyphenyls, alkyl aromatics and polyphenyls.

Lubricant Requirements

Heat transfer fluids should have very low vapor pressure, high flash points, low volatility, good lubricity, high specific heats and thermal conductivities and must be resistant to oxidation and corrosion. Formulated polyalphaolefins and alkylated naphthalene should meet these requirements and can be substituted for mineral oils and other synthetic hydrocarbons in heating and cooling systems. The broad range of viscosities gives the user a choice of lubricants for the specific system being utilized.

Basestock Formulations (Weight %)

	VG 5	VG 20	VG 32	VG 32	VG 68	Flash Point COC, °C	Autoignition Temperature[1], °C
SpectraSyn™ 2	100	–	–	–	–	157	350
SpectraSyn™ 4	–	100	–	–	–	220	351
SpectraSyn™ 6	–	–	100	–	–	246	378
Synesstic™ 5	–	–	–	100	–	222	348
SpectraSyn™ 10	–	–	–	–	100	266	391*

[1]Single sample determinations

*Calculated

Additive Requirements

A typical heat transfer fluid formulation would contain a total of 0.5 - 2% of the following additives with the remainder, depending on the viscosity grade, being the basestocks in the ratios shown above.

Corrosion Inhibitor	*Rust Inhibitor*
Oxidation Inhibitor	*Antifoamant*

Esterex™ esters are not available in the Europe, Africa and Middle East Regions.

APPENDIX – NOTES AND TABLES

CLICK ON PAGE TITLE TO VIEW

I. ADDITIVE GLOSSARY

Many kinds of chemical additive agents are used in the manufacture of high-quality oils. They are either single-purpose materials or multipurpose materials. Listed below are descriptions of some commonly used additive types.

Adhesive Agents
The tacky, stringy materials which help form and retain uniform films on metal surfaces.

Antiwear Agents
Such materials adsorb or concentrate on metal surfaces to form films which minimize the direct metal-to-metal contact. The name applies to materials which enhance the antiwear characteristics of petroleum oils to permit loadings of double or triple that which can be handled by straight petroleum oils. These materials are nonstaining and noncorrosive.

Defoamants
When added to fluids, defoamants will promote rapid breakup of foam bubbles by weakening the oil films between the foam bubbles.

Demulsifiers
Assist the natural ability of the oil to separate rapidly from water; help inhibit rust.

Detergents
When added to oils, these neutral to overbased (high alkalinity), metallic detergents, which carry extra neutralization and cleanliness power, can reduce the level of acidic materials generated when burning high-sulfur fuel, and help keep the engine clean.

Dispersants
Suspend organic deterioration products in the lubricant to minimize their precipitation as harmful deposits.

Extreme-Pressure Agents
These materials are more active than the antiwear agents, and usually react with the metal surface to provide sufficient antiwear material to carry even heavier loads than the antiwear agents. Automotive hypoid gears require lubricants which contain very active extreme-pressure agents.

Friction Modifiers
A general category of materials that are used to alter the frictional characteristics of a lubricant. They may be used to increase the lubricity or slipperiness where coefficient of friction may be important, or to improve fuel economy/energy conservation.

Oxidation Inhibitors
Some additive agents function as peroxide decomposers, chain stoppers, and/or metal deactivators.

- Peroxide decomposers destroy the precursor of radical sources by converting the peroxides into harmless compounds.
- Chain stoppers interrupt the chain reaction between oxygen and hydrocarbon radicals to prevent or slow the formation of acidic materials, propagated materials, and sludges.
- Metal deactivators retard the oxidation-promoting catalytic effect of metals in a lubricating system. The metal surfaces or particles are covered by the agent, which acts as a barrier to prevent the catalytic effect. The most catalytically active metal is copper, the second is lead, and the third is iron.

Pour Point Depressants
These improve the low-temperature fluidity of mineral oils and reduce wax formation at low temperatures.

Rust Inhibitors
The primary guide to rust inhibition is the ASTM D 665 Rust Test, which is a pass/fail test. Most lubricating oils contain rust inhibitors to enhance their ability to minimize rusting.

Viscosity Index Improvers
When added to oils, these high-molecular-weight polymers improve the viscosity index by coiling and uncoiling in response to temperature. They do not affect the pour point at low temperature, while providing sufficient viscosity at high temperature.

II. ADDITIVE PRODUCT MATRIX
ADDITIVES FOR TYPICAL INDUSTRIAL LUBRICANT FORMULATIONS

Additive/Application	Compressor Lubes Ester-based	Compressor Lubes PAO-based	Refrig. Lubes PAO-based	Industrial Gear Lubes	Hydraulic Fluids (all)	Industrial Oven Chain Lubricants	Mist Lubricants	Paper Machine Oils	Synthetic Greases	Turbine Oils
Antiwear	Y	Y	Y	Y/N	Y	Y	Y	Y	Y	Y
Antifoamant	Y	Y		Y	Y	Y	Y	Y		Y
Corrosion Inhibitor	Y	Y		Y	Y	Y	Y		Y/N	Y
Demulsifier	Y	Y		Y	Y		Y	Y		Y
Detergent				Y/N		Y				
Dispersant	Y	Y/N		Y/N				Y/N		Y
Extreme Pressure				Y	Y/N	Y		Y	Y	Y/N
Friction Modifier	Y/N	Y		Y/N	Y/N	Y/N		Y	Y/N	Y/N
Oxidation Inhibitor	Y	Y	Y	Y	Y	Y		Y	Y	Y
Rust Inhibitor	Y			Y	Y				Y	Y
Other									Soap/Polymer	

Typical Treat Rate Ranges, Wt.%	
Industrial Lubes	0.5 - 6.0%
Industrial Gear Oils	1.0 - 5.0%
Refrigeration Lubes	0.1 - 2.0%

Source: ExxonMobil Data

III. SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) VISCOSITY GRADES FOR ENGINE OILS

SAE Viscosity Grade	Low-Temperature (°C) Cranking Viscosity[1] (cP) Max	Low-Temperature (°C) Pumping Viscosity[2] (cP) Max with No Yield Stress	Low-Shear-Rate Kinematic Viscosity[3] (cSt) at 100°C Min	Low-Shear-Rate Kinematic Viscosity[3] (cSt) at 100°C Max	High-Shear-Rate Viscosity[4] (cP) at 150°C Min
0W	6,200 at -35	60,000 at -40	3.8	–	–
5W	6,600 at -30	60,000 at -35	3.8	–	–
10W	7,000 at -25	60,000 at -30	4.1	–	–
15W	7,000 at -20	60,000 at -25	5.6	–	–
20W	9,500 at -15	60,000 at -20	5.6	–	–
25W	13,000 at -10	60,000 at -15	9.3	–	–
20	–	–	5.6	<9.3	2.6
30	–	–	9.3	<12.5	2.9
40	–	–	12.5	<16.3	2.9[5]
40	–	–	12.5	<16.3	3.7[6]
50	–	–	16.3	<21.9	3.7
60	–	–	21.9	<26.1	3.7

(1) ASTM D 5293
(2) ASTM D 4684; note that the presence of any yield stress detectable by this method constitutes a failure regardless of viscosity.
(3) ASTM D 445
(4) ASTM D 4683, CEC L-36-A-90 (ASTM D 4741), or ASTM D 5481
(5) 0W-40, 5W-40, and 10W-40
(6) 15W-40, 20W-40, 25W-40, and 40

Version 2004

Source: SAE

IV. SOCIETY OF AUTOMOTIVE ENGINEERS J306 VISCOSITY GRADES FOR GEAR OILS

SAE Grade	Maximum Temperature for BF Viscosity 150,000 mPa-s(cP)[1]	Kinematic Viscosity, 100°C, mm^2/s (cSt)[2] Min.[3]	Max.
70W	-55°C	4.1	–
75W	-40°C	4.1	–
80W	-26°C	7.0	–
85W	-12°C	11.0	–
80	–	7.0	<11.0
85	–	11.0	<13.5
90	–	13.5	<18.5
110	–	18.5	<24.0
140	–	24.0	<32.5
190	–	32.5	<41.0
250	–	41.0	–

[1] ASTM D 2983
[2] ASTM D 445
[3] Limits must also be met after testing in CEC L-45-T-93 Method C (20 hours).

Source: SAE

V. GREASE CONSISTENCY CLASSIFICATION: NATIONAL LUBRICATING GREASE INSTITUTE (NLGI) AMERICAN STANDARD LUBRICATING GREASE CLASSIFICATION

Grade	60-Stroke Worked Penetration @ 77°F (25°C)
NLGI No. 000	445-475
NLGI No. 00	400-430
NLGI No. 0	355-385
NLGI No. 1	310-340
NLGI No. 2	265-295
NLGI No. 3	220-250
NLGI No. 4	175-205
NLGI No. 5	130-160
NLGI No. 6	85-115

The grades are defined as ranges of the values of the 60-stroke worked penetration, in tenths of millimeters, as determined by the ASTM Designation D 217, "Cone Penetration of Lubricating Grease."

Source: NLGI

VI. VISCOSITY CONVERSION TABLE

Kinematic	SUS	Engler	Redwood No. 1 Sec.	Kinematic	SUS	Engler	Redwood No. 1 Sec.	Kinematic	SUS	Engler	Redwood No. 1 Sec.
2	32.6	1.14	30.8	46	214	6.15	190	240	1112	32	990
3	36.0	1.22	33.2	50	233	6.65	207	250	1159	33	1030
4	39.1	1.31	35.8	55	256	7.25	228	260	1205	34	1070
5	42.5	1.40	38.4	60	279	7.9	248	270	1251	36	1110
6	45.7	1.48	41.0	65	302	8.6	268	280	1297	37	1150
7	49.0	1.56	43.7	70	325	9.25	286	290	1344	38	1190
8	52.0	1.65	46.5	75	349	9.85	307	300	1390	40	1230
9	55.7	1.74	49.2	80	372	10.5	329	315	1460	41	1300
10	59.0	1.83	52.1	85	395	11.2	349	330	1529	43	1350
11	62.5	1.92	55.2	90	418	11.8	370	350	1622	46	1440
12	66.2	2.02	58.4	95	442	12.5	390	370	1715	49	1520
13	70.0	2.12	61.6	100	465	13.2	410	390	1807	51	1600
15	77.5	2.32	68.2	110	511	14.5	450	410	1900	54	1690
17	85.5	2.55	75.2	120	558	15.8	490	430	1990	57	1770
19	94	2.77	82.8	130	605	17.1	530	450	2090	59	1850
21	100	3.00	90.4	140	649	18.4	570	470	2180	62	1930
23	111	3.23	98	150	695	19.7	620	490	2270	64	2010
25	120	3.46	106	160	742	21.0	660	500	2320	66	2050
28	133	3.83	117	170	788	22.5	700	550	2540	72	2260
30	142	4.09	125	180	834	24.0	740	600	2780	79	2460
33	155	4.46	137	190	881	25.0	780	650	3010	86	2670
35	164	4.71	145	200	927	26.0	820	700	3240	92	2880
38	178	5.10	157	210	973	28.0	860	750	3470	99	3080
40	187	5.35	166	220	1020	29.0	900	800	3700	105	3280
43	200	5.75	178	230	1066	30.0	940	–	–	–	–

Source: ExxonMobil Data

VII. DEGREES API CORRESPONDING TO SPECIFIC GRAVITIES AT 60/60°F AND POUNDS PER GALLON

Degrees API	Specific Gravity (S.G.)	Pounds Gallons	Degrees API	Specific Gravity (S.G.)	Pounds Gallons	Degrees API	Specific Gravity (S.G.)	Pounds Gallons
1.36	1.065	8.870	14.4	0.970	8.078	30.2	0.875	7.286
1.99	1.060	8.829	15.5	0.965	8.036	31.1	0.870	7.244
2.62	1.055	8.787	15.9	0.960	7.995	32.1	0.865	7.203
3.26	1.050	8.745	16.7	0.955	7.953	33.0	0.860	7.161
3.91	1.045	8.704	17.5	0.950	7.911	34.0	0.855	7.119
4.56	1.040	8.662	18.2	0.945	7.870	35.0	0.850	7.078
5.21	1.035	8.620	19.0	0.940	7.828	36.0	0.845	7.036
5.88	1.030	8.578	19.8	0.935	7.786	36.9	0.840	6.994
6.55	1.025	8.537	20.6	0.930	7.745	38.0	0.835	6.952
7.23	1.020	8.495	21.5	0.925	7.703	39.0	0.830	6.911
7.91	1.015	8.453	22.3	0.920	7.661	40.0	0.825	6.869
8.60	1.010	8.412	23.1	0.915	7.620	41.0	0.820	6.827
9.30	1.005	8.370	24.0	0.910	7.578	42.1	0.815	6.786
10.00	1.000	8.328	24.8	0.905	7.536	43.2	0.810	6.744
10.70	0.995	8.287	25.7	0.900	7.494	44.3	0.805	6.702
11.4	0.990	8.245	26.6	0.895	7.453	45.4	0.800	6.661
12.2	0.985	8.203	27.5	0.890	7.411	–	–	–
12.9	0.980	8.162	28.4	0.885	7.369	–	–	–
13.6	0.975	8.120	29.3	0.880	7.328	–	–	–

Source: ExxonMobil Data

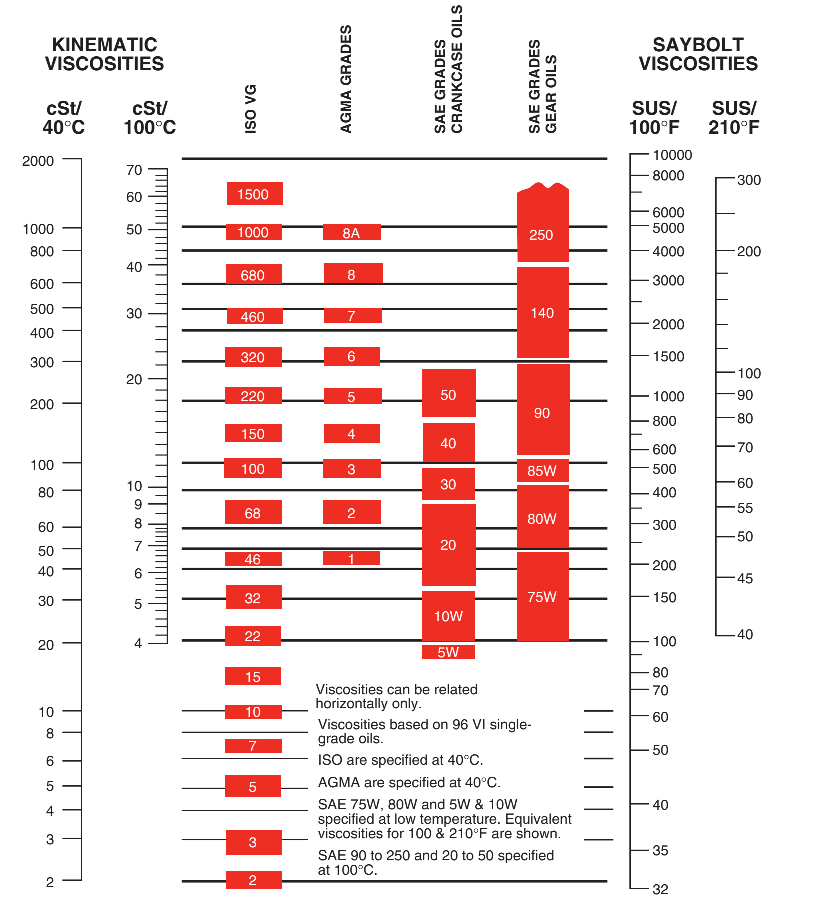
ISO VISCOSITY CLASSIFICATION SYSTEM

Many petroleum products are graded according to the ISO Viscosity Classification System, approved by the International Standards Organization (ISO). Each ISO viscosity grade number corresponds to the midpoint of a viscosity range expressed in centistokes (cSt) at 40°C. For example, a lubricant with an ISO grade of 32 has a viscosity within the range of 28.8 – 35.2, the midpoint of which is 32.

Rule of Thumb: The comparable ISO grade of a given product whose viscosity in SUS at 100°F is known can be determined by using the following conversion formula:

SUS @ 100°F ÷ 5 = cSt @ 40°C

VIII. VISCOSITY CLASSIFICATION EQUIVALENTS



Note: cSt=mm²/s
Source: ExxonMobil Data

IX. INTERNATIONAL STANDARDS ORGANIZATION (ISO) VISCOSITY CLASSIFICATION

ISO Viscosity Grade (ISO VG)	Kinematic Viscosity cSt @40°C (104°F) midpoint	Kinematic Viscosity Limit cSt @40°C (104°F) minimum	Kinematic Viscosity Limit cSt @40°C (104°F) maximum
2	2.2	1.98	2.42
3	3.2	2.88	3.52
5	4.6	4.14	5.06
7	6.8	6.12	7.48
10	10	9.00	11.0
15	15	13.5	16.5
22	22	19.8	24.2
32	32	28.8	35.2
46	46	41.4	50.6
68	68	61.2	74.8
100	100	90.0	110
150	150	135	165
220	220	198	242
320	320	288	352
460	460	414	506
680	680	612	748
1000	1000	900	1100
1500	1500	1350	1650
2200	2200	1980	2420
3200	3200	2880	3520

Source: ExxonMobil Data

XII. ACRONYMS

ACEA
Association des Constructeurs Europeens d'Automobiles (European Auto Manufacturers Association)

AGMA
American Gear Manufacturers Association

AN
Alkylated Naphthalene

API
American Petroleum Institute

ASTM
American Society for Testing and Materials

CCS
Cold Cranking Simulator

COC
Cleveland Open Cup

cP
Centipoise

cSt
Centistoke

EP
Extreme Pressure

FZG
Forschungstelle fur Zahnrader und Getriebebau (Research Institute for Gears and Gearboxes)

High VI
High Viscosity Index

HTHS
High Temperature, High Shear

HVI PAO
High Viscosity Index Polyalphaolefins

ILSAC
International Lubricant Standardization and Approval Committee

ISO
International Standards Organization

JASO
Japan Automotive Standards Organization

KV
Kinematic Viscosity

MRV
Minirotary Viscometer

NMMA
National Marine Manufacturers Association

NLGI
National Lubricating Grease Institute

OECD
Organisation for Economic Co-operation and Development

OEM
Original Equipment Manufacturer

Pa
Pascal

PAO
Polyalphaolefins

PIB
Polyisobutylene

SAE
Society of Automotive Engineers

SG
Specific Gravity

SSI
Shear Stability Index

SUS (or SSU)
Saybolt Second Universal

TCW-3
Water-cooled Two-cycle Engine Oil Specification

TAN
Total Acid Number

VG
Viscosity Grade

VI
Viscosity Index

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