Dealer Training Series

Lubrication Fundamentals

An Introduction to the Principles of Lubrication | Presented by AMSOIL INC.

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Lubrication Fundamentals: Section 1
Lubrication Basics

Introduction

The following course is an introduction to lubricating fluids and the principles of lubrication. It is ideal for those who service mechanical equipment and those marketing lubricants.

Section 1 discusses the different functions of lubricants. Types of lubrication, lubrication failure modes and the mechanical needs lubricants fulfill.

Section Objectives

After studying Section 1, you should understand and be able to explain the following terms and concepts:

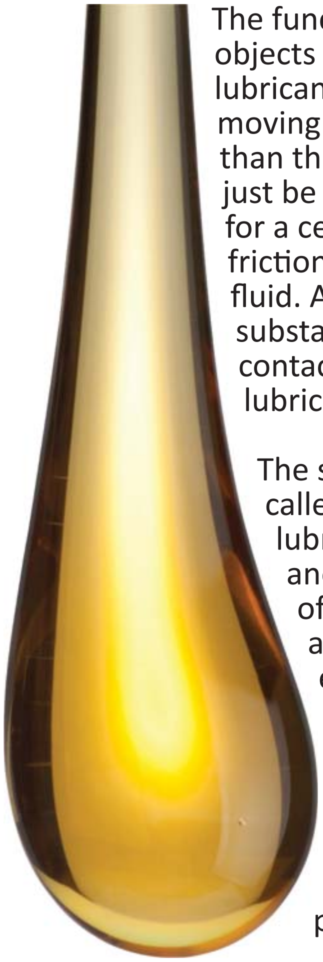
1. The primary purpose of a lubricant
2. The negative effects of friction in mechanical equipment
3. The seven functions of a lubricant
4. The four types of fluid lubrication
5. The three mechanical needs for lubricants
6. The four lubrication failure mechanisms
7. The Right Principle
8. The four methods for recommending AMSOIL products

Section Keywords

The following keywords will be explained in this section. Pay particular attention to their meanings as these concepts will serve as building blocks for future lessons.

Additives
Anti-Wear Additives
Boundary Lubrication
Detergents
Dispersants
Elastohydrodynamic Lubrication
Film Strength
Friction
Hydrodynamic Lubrication
Lubricant
Lubricity
Mixed-Film Lubrication
R&O Fluids
Solvency
The Right Principle
Tribology

Lubricants and Their History



The function of a lubricant is to reduce friction and allow objects in contact to move easily against each other. A lubricant reduces wear by creating a boundary between moving surfaces. Modern-day lubricants are more complex than their predecessors, which were mainly designed to just be slippery. Today's lubricants are engineered to allow for a certain amount of slipperiness and have controlled friction qualities to them as well, such as in a transmission fluid. A ***lubricant*** may be any substance. If the job of a substance is to create a film between surfaces to prevent contact and reduce friction, it can be considered a lubricant.

The study of how surfaces interact in relative motion is called ***tribology***. Friction, wear, contact mechanics and lubrication are all important aspects of tribology. While ancient cultures may not have realized the complexity of modern tribology, they did develop sophisticated and novel methods of lubrication to improve efficiency in their everyday tasks.

As early as the mid-1400s B.C., Egyptians used animal fats to lubricate sleds that moved heavy objects. Lubricants were used in Roman battle ships to lubricate moving platforms that used balls and rollers, in 50 A.D. In China, vegetable oils became a popular lubricant around 780 A.D.

Animal fats and vegetable oils continued to be preferred well into the mid-1800s, but by the 1860s lubricants were obtained from petroleum crude. In today's market, chemically synthesized stocks are a growing alternative to mineral oils. Though first recognized in the 1920s, synthesized stocks have more recently gained global attention for their ability to withstand the demands of today's technologies.

To better understand these demands, a better understanding of friction is necessary.

Understanding Friction

Friction is the resistance resulting from rubbing one object against another. A simple example of friction is the heat generated when rapidly rubbing your hands together. Note that the faster and harder you rub them together, the more rapid and greater the heat generated.

Friction is both a positive and negative force in our daily lives; it's an essential force for everyday, mundane tasks such as walking, where friction gives you the ability to create traction between yourself and the ground and move forward. It's also a force in such systems as automobile engines, where it must be

overcome in order to operate efficiently.

Another example of positive friction is in the use of knots, such as in a shoelace or the knots of a marine tether. Friction keeps knots in place, allowing people to walk without tripping over their laces and preventing boaters from losing their boats to the moving current. The friction that occurs in motors is an example of harmful friction because of the excess heat produced and the physical wearing away of components.

The most common substance used to reduce friction is a fluid or semi-fluid material. The fluid materials maintain a layer of separation, preventing components from contacting one another. Separation is maintained because the fluid resists compression; even at only a few millionths of an inch, a fluid can eliminate contact in many instances. The inherent ability of oil to maintain component separation is called ***lubricity***. Lubricity, sometimes referred to as ***film strength***, is the lubricant's capacity for reducing friction. Lubricity is not the same across all fluids; it can vary dramatically from one fluid to another.

In today's lubricants, base stocks are primarily composed of crude oil. Chemical compounds called ***additives*** are added to the base stock to provide specific properties to the fluid. Often, these additives are used to further minimize friction or wear beyond the capabilities of the base oil. These additives offer protection when the lubricating fluid cannot maintain component separation. They may also address concerns beyond the capabilities of the fluid itself. For example, these compounds might clean, protect or control how contaminants such as water and other foreign objects act in a lubricant.

How Lubricants Work

While friction and wear reduction are a lubricant's primary functions, it also serves other important functions. To better understand specifically how lubricants work, one needs to understand why they are used, what kinds of lubrication exist and what specific applications require lubrication.

The Seven Functions of Lubrication

A lubricant must satisfy all of the following seven functions.

Minimize Friction

Lubricants reduce contact between components, minimizing friction and wear.

Clean

Lubricants maintain internal cleanliness by suspending contaminants within the fluid or by preventing the contaminants from adhering to components. Base oils possess a varying degree of solvency that assists in maintaining internal cleanliness. Solvency is the ability of a fluid to dissolve a solid, liquid or gas. While the solvency of the oil is important, detergents and dispersants play a key role. Detergents are additives that prevent contaminants from adhering to components, especially hot components such as pistons or piston rings. Dispersants are additives that keep contaminants suspended in the fluid. Dispersants act as a solvent, helping the oil maintain cleanliness and prevent sludge formation.

Cool

Reducing friction minimizes heat in moving parts, which lowers the overall operating temperature of the equipment. Lubricants also absorb heat from contact surface areas and transport it to a location to be safely dispersed, such as the oil sump. Heat transfer ability tends to be a trait of the base oil's thickness – lighter oils tend to transfer heat more readily.

Seal

Lubricants act as a dynamic seal in locations like piston rings and cylinder contact areas to prevent contamination.

Dampen Shock

A lubricant can cushion the blow of mechanical shock. A highly functional lubricant film can resist rupture and absorb and disperse these energy spikes over a broad contact area. As the mechanical shock to components is dampened, wear and damaging forces are minimized, extending the component's overall operating life.

Protect

A lubricant must have the ability to prevent or minimize internal component corrosion. Lubricants accomplish this either by chemically neutralizing corrosive products or by creating a barrier between the components and the corrosive material.

Transfer Energy

Because lubricants are incompressible, they can act as an energy-transfer medium, such as in hydraulic equipment or valve lifters in an automotive engine.

The Three Types of Fluid Lubrication

Although the reduction of friction by using a fluid appears simple, it is actually very complex. Fluid lubrication can be divided into three basic types: full-film, thin-film and solid lubrication. Full-film lubrication consists of four sub-types: hydrodynamic lubrication, elastohydrodynamic (EHD)-film, hydrostatic-film and squeeze-film. Thin-film lubrication consists of mixed-film and boundary layer sub-types.

Hydrodynamic Lubrication (HL)

Hydrodynamic lubrication is a form of full-film lubrication and occurs when the lubricant creates a complete barrier between two rolling or sliding surfaces so there is no metal-to-metal contact. The movement of the rolling or sliding action causes the film to become thicker and pressurized, which prevents the surfaces from touching.

Hydrodynamic lubrication creates the ideal scenario: a full film of separation between moving parts. When the two surfaces are moving in opposite directions, the fluid immediately next to each surface will travel at the same speed and direction as the surface.

If two parts are moving in the same direction, a full hydrodynamic film can be formed by wedging a lubricant between the moving parts. Known as

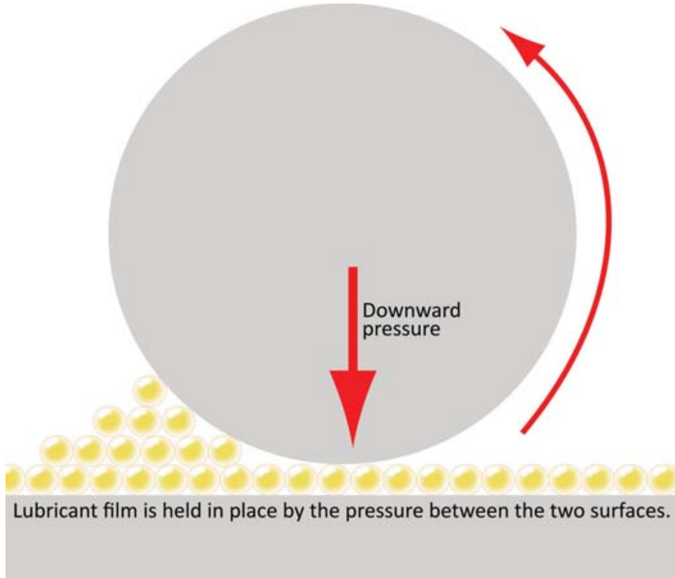


Figure 1.1
Hydrodynamic lubrication

wedging film action, this principle allows large loads to be supported by the fluid. It works much like a car tire hydroplaning on a wet road surface: the fluid accumulates in front of the surface (tires) faster than it can be pushed or channeled away.

During reciprocating motion, where the speeds of the relative surfaces eventually reach zero as the direction changes, the wedging of the lubricant is necessary to maintain hydrodynamic lubrication.

Some factors, such as load increases, can prevent hydrodynamic lubrication by decreasing the oil film thickness, allowing metal-to-metal contact to occur.

Elastohydrodynamic Lubrication (EHD or EHL)

Elastohydrodynamic lubrication is a form of full-film lubrication and occurs when the lubricant reacts to the pressure or load and resists compression, functioning as if it were harder than the metal surface it supports. This pressure acts upon the metal surface, causing it to deform and creating

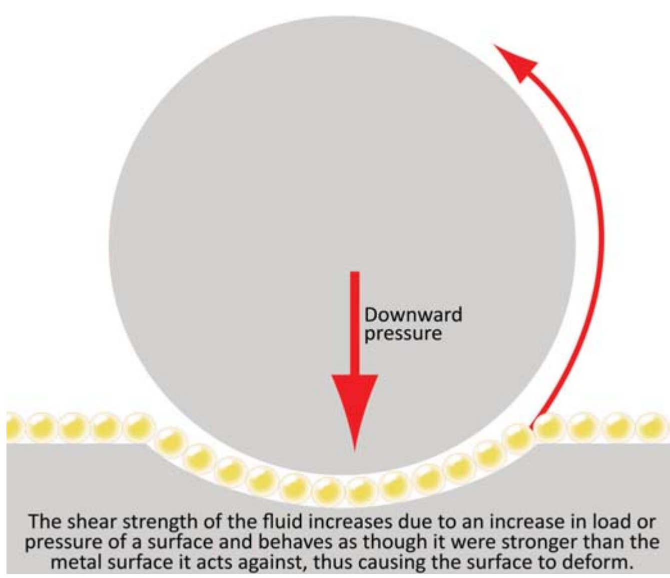


Figure 1.2
Elastohydrodynamic lubrication

more surface area for the lubricant to contact.

EHD occurs in the area approaching the ***stress zone***, the area where the most pressure or load affects the component. In roller bearings, for example, the metal surface deforms from the extreme pressure of the lubricant (see Figure 1.2).

Hydrostatic-Film Lubrication

Hydrostatic-film lubrication is common in heavily loaded applications that require a supply of high-pressure oil film. The high pressure in hydrostatic-film lubrication ensures that the required film thickness will be maintained to support a heavy load during extreme operation. Hydrostatic-film lubrication is able to maintain a fluid film under high-load and low-speed conditions, such as those experienced at equipment startup.

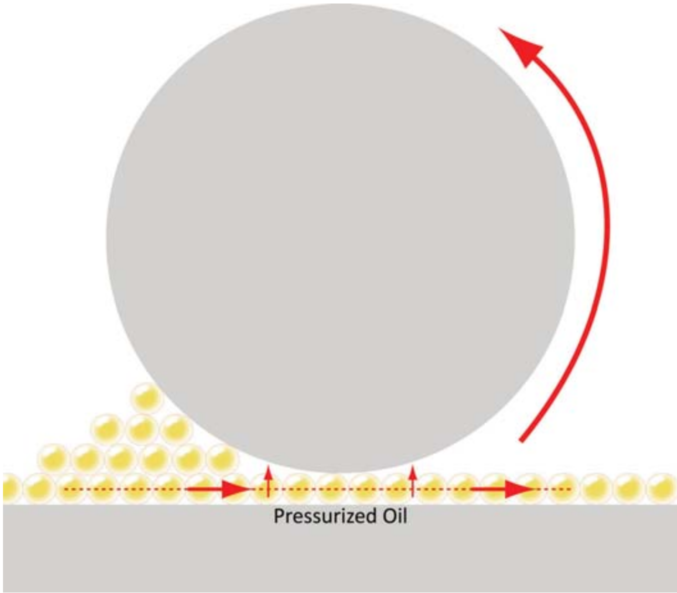


Figure 1.3
Hydrostatic-film lubrication

Squeeze-Film Lubrication

Squeeze-film lubrication is a form of full-film lubrication that results from pressure that causes the top load plate to move toward the bottom load plate. As these surfaces move closer together, the oil moves away from the heavily loaded area. As the load is applied, the viscosity of the lubricant increases, enabling the oil to resist the pressure to flow out from between the plates. Eventually, the lubricant will move to either side, resulting in metal-to-metal contact. A piston pin bushing is a good example of squeeze-film lubrication.

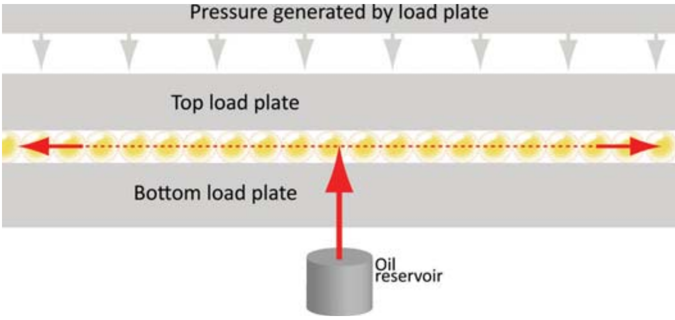


Figure 1.4
Squeeze-film lubrication

Boundary Lubrication

No surface is truly smooth, even when polished to a mirror finish. The irregularities, or asperities, on every surface may be so small that they are only visible under a microscope. When two highly polished surfaces meet, only some of these asperities on the surfaces touch, but when force is applied at right angles to the surfaces (called a normal load), the number of contact points increases. ***Boundary lubrication*** is a form of thin-film lubrication and occurs when a lubricant's film becomes too thin to prevent contact between surfaces and contact between the surface's asperities occurs. Excessive loading, high speeds or a change in the fluid's characteristics can result in boundary lubrication.

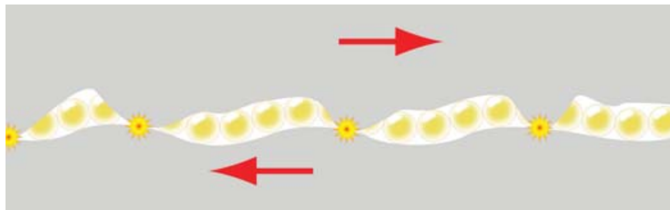


Figure 1.5
Boundary lubrication

Boundary lubrication often occurs during the start-up and shut-down of equipment. In these cases, chemical compounds enhance the properties of the lubricating fluid to reduce friction and provide wear protection.

Mixed-Film Lubrication

Mixed-film lubrication is considered a form of thin-film lubrication, although it is actually a combination of hydrodynamic and boundary lubrication. In mixed-film lubrication, only occasional asperity contact occurs.

Solid-Film Lubrication

Solid-film lubrication is used in applications that are difficult to lubricate with oils and greases. To manage these difficult applications, solid- or dry-film lubrication is applied where the solid or dry material attaches to the surface to reduce roughness. Solid-film lubricants fill the valleys and peaks of a rough surface to prevent metal-to-metal contact. A common form of solid-film lubrication is Teflon® coating.

The Four Wear Mechanisms

Abrasive Wear

Abrasive wear starts with particles that originate as contaminants from outside the engine, such as wearing components or soot. These contaminants grind and scrape metal surfaces of the engine, causing abrasive wear. Most abrasive wear contaminants can be removed by a good oil filtering system.

Corrosive Wear

Corrosive wear, sometimes referred to as chemical wear, results from chemical attack or rubbing action on a metal surface. Cylinder-wall wear is a good example of wear from a combination of metal-surface rubbing and chemical corrosion.

Adhesive Wear
Adhesive wear is a result of metal-to-metal contact under conditions of high load, speed or temperature. It results from localized bonding between surface asperities as they slide against each other, causing scuffing, scoring or seizure. Localized bonding leads to particles from surfaces becoming transferred to the opposing surface.

Fatigue Wear
Fatigue wear, also referred to as rolling-contact fatigue, occurs when there is a lubricating film in place; however, regular stress on the surface causes fractures over time. Fatigue wear occurs predominantly in rolling-element bearings due to the repetitive stresses they endure.

Three Mechanical Needs for Lubrication

Regardless of equipment type, there are generally three basic types of components that require lubrication: bearings, gears and cylinders. Nearly all equipment and components fall under one of the three categories.

Bearings
Bearings allow a surface to rotate or slide when under load. The word bearing means to bear or support a shaft or surface. Bearings are categorized into two types: plain bearings and rolling-element bearings.

Plain bearings, such as sliding, journal, sleeve or bushing bearings, are generally softer than the shaft or surface being supported. This protects the shaft at the expense of the bearing. Softer bearing materials have a tendency to collect debris that the lubricant must overcome. Plain bearings function best under hydrodynamic lubrication (full-film) or boundary (thin-film) lubrication. Oils and greases are typically used to lubricate these types of bearings.

Rolling-element bearings, also referred to as anti-friction bearings, are a class of bearings where elements such as balls, rollers or needles keep a moving surface separate from a stationary surface. They are generally referred to by the shape of the rolling elements they contain: ball bearing, roller bearing, needle bearing or tapered-roller bearing. These types of bearings commonly function under elastohydrodynamic lubrication. When lubricated properly, the load capacity and life of such bearings is limited primarily by the strength of the bearing steel. Oils or greases typically lubricate these types of bearings.

Typical materials used in the construction of modern bearings are bronze, lead, copper, aluminum, nylon and plastic. Older bearings containing alloys of tin, copper and antimony are called babbit, soft or white-metal bearings.

Gears

Gears are used to transfer power and/or motion from the power source to the application. They are also used to change the direction, speed or rotational force (torque) of that motion. Gears come in many configurations that have different lubrication requirements depending on their intended application. Gears are most often lubricated with oils; however, thin greases (a mixture of oil and a thickener) may also be used.

Spur, Helical and Herringbone Gears

Spur, Helical and Herringbone gears are typically lubricated using what are commonly referred to as rust and oxidation (R&O) oils. ***R&O fluids*** are base oils with rust and oxidation inhibitors. Depending on the application, a mild extreme-pressure (EP) additive may be called for.

Figure 1.6
Spur gear, helical gear and herringbone gear

Figure 1.7
Hypoid gear

Hypoid Gear

Hypoid gear sets are typically used in automotive components such as the differential. Sliding pressures and shock-loading require the use of high levels of EP additives (API GL-4 or GL-5 performance level). Generally, a fluid's API number roughly estimates its concentration of EP additives.

Figure 1.8
Bevel gear

Bevel Gear

Bevel gear sets also require the use of EP additives; however, the level is less than the level required for hypoid gears.

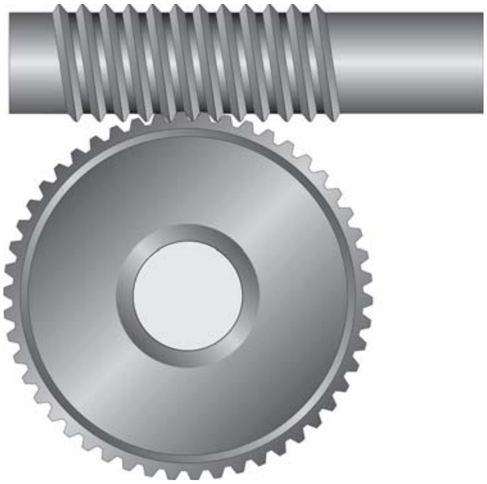


Figure 1.9
Worm gear

Worm Gear

Worm gears typically use high-viscosity oils containing friction modifiers and very low EP additive levels. Because these gears may be brass or bronze material, EP additives should be avoided to prevent corrosion.

Many applications use a combination of gear types. The lubricant meeting the requirements of the most demanding gear will be the determining factor in deciding which lubricant to use.

Figure 1.10
Hydraulic cylinders are common in heavy-duty equipment.

Cylinders

Cylinders typically require minimal amounts of lubrication. Higher viscosity R&O fluids generally meet a cylinder's requirements. In cases where sliding loads are high (two-stroke gasoline engines), friction modifiers may be necessary.

Defining "The Right Principle"

When determining the proper lubricant for an application, the key is the ability to satisfy all equipment needs, such as compatibility with a particular method of supplying or applying the lubricant. Some modern methods include any combination of the following techniques: pouring, dripping, wicking, immersion, brushing, spraying, pumping and impregnation.

Other factors include how, where and when the system is being used. The composition of the material used within the system can also dictate lubrication requirements. A seal or copper component, for example, might require very specific lubrication treatments to avoid damage.

Careful consideration of how a lubricant is to be applied provides insight as to what properties, such as viscosity and clinging tenacity, the lubricant may require. Thinking about the possibilities should always lead to applying the ***Right Principle***, which is using the right lubricant, in the right place, at the right time.

When a prospect is ready to buy an AMSOIL lubricant, determine which product and how much is needed by checking with the equipment manufacturer or consulting the owner's manual.

Lubrication Fundamentals: Section 2
The Composition of Lubricants

Introduction

Section 2 details the composition of lubricants, beginning with a brief discussion of crude petroleum and briefly touching on the refining process. The basic components and the nature of mineral- and synthetic-based lubricants are discussed, with an emphasis on the base stocks AMSOIL uses in its synthetic lubricants, followed by a discussion of why those stocks are chosen.

Section Objectives

After studying Section 2, you should understand and be able to explain the following terms and concepts:

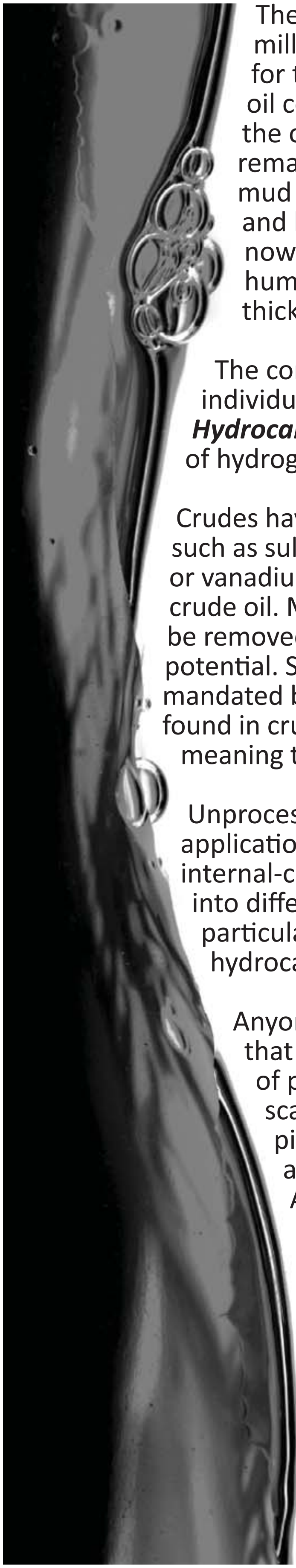
1. How crude petroleum was created
2. The refining process and the methods used
3. The base oil groups developed by the API
4. What constitutes a synthetic- versus a petroleum-based product
5. The beneficial performance characteristics of a synthetic lubricant over a conventional mineral-oil lubricant
6. The difference between how mineral oil lubricants are developed and how synthetic lubricants are developed
7. The molecular advantages of synthetic hydrocarbons
8. The two primary functions of additives

Section Keywords

The following keywords are defined in this section. Pay particular attention to their explanations as these concepts will serve as building blocks for future lessons.

Additives
Diesters
Fractions
Hydrocarbons
Naphthenic Oil
Paraffinic Oil
Polyalphaolefins (PAOs)
Polyglycols (PAGs)
Polyol Esters
Refining
Saturate Level
Silicone Fluids
Synthetic Blends
Synthetic Hydrocarbons
Synthetic Oil

Defining Base Oil Properties



The crude petroleum oil used today dates back millions of years. There are two predominant theories for the origin of crude oil. One suggests that crude oil comes from carbon deposits deep in the earth; the other suggests that it has been created from the remains of tiny animals and plants that settled with mud and silt. Over millions of years of intense pressure and heat, this organic matter turned into what is now known as crude oil. Despite crude oil's origins, humankind has found many ways to harness this dark, thick, stinky substance.

The composition of crude oil is complex, containing individual hydrocarbons or hydrocarbon compounds. ***Hydrocarbons*** are organic compounds that consist entirely of hydrogen and carbon atoms.

Crudes have varying amounts of elemental compounds such as sulfur, nitrogen, oxygen, and metals such as nickel or vanadium. Water-containing salts can also be found in crude oil. Many materials inherent to crude petroleum must be removed by a ***refining*** process to increase the oil's use potential. Some materials, such as sulfur, must be removed as mandated by environmental regulations. All of the materials found in crude oil add complexity to the refining process, meaning there is a higher cost to removing these materials.

Unprocessed crude can be used, but there are limited applications for it, such as in power plants and some internal-combustion engines. Most often crude is distilled into different ***fractions***. Fractions are batches of a particular substance, in this case, different molecules of hydrocarbons.

Anyone who has driven past an oil refinery will recall that these plants appear to be very large mazes of piping and other large units with smoke stacks scattered about. The complex maze consists of piping, distillation units, furnaces, hydrocrackers and a number of other units needed to refine crude oil. All of these components are necessary to separate the hundreds of different types of hydrocarbon molecules into simpler, more usable forms.

A detailed discussion of the oil refining process is beyond the scope of this course, but Figure 2.1 on the following page does a good job of illustrating the process. As crude oil begins the refining process, it enters a distillation tube. From there the separated molecules enter additional treatment centers to be further broken down into usable oils and substances such as sulfur, butanes, jet fuel, kerosene, diesel oil, fuel oil, petroleum coke, asphalt and gasoline.

The refining of crude oils can produce a variety of lubricant types of varying quality and viscosity grades. These lubricants can be refined to some degree to maximize their beneficial characteristics and minimize those that are not desirable; however, the cost of such refining is usually too great to achieve acceptable profits.

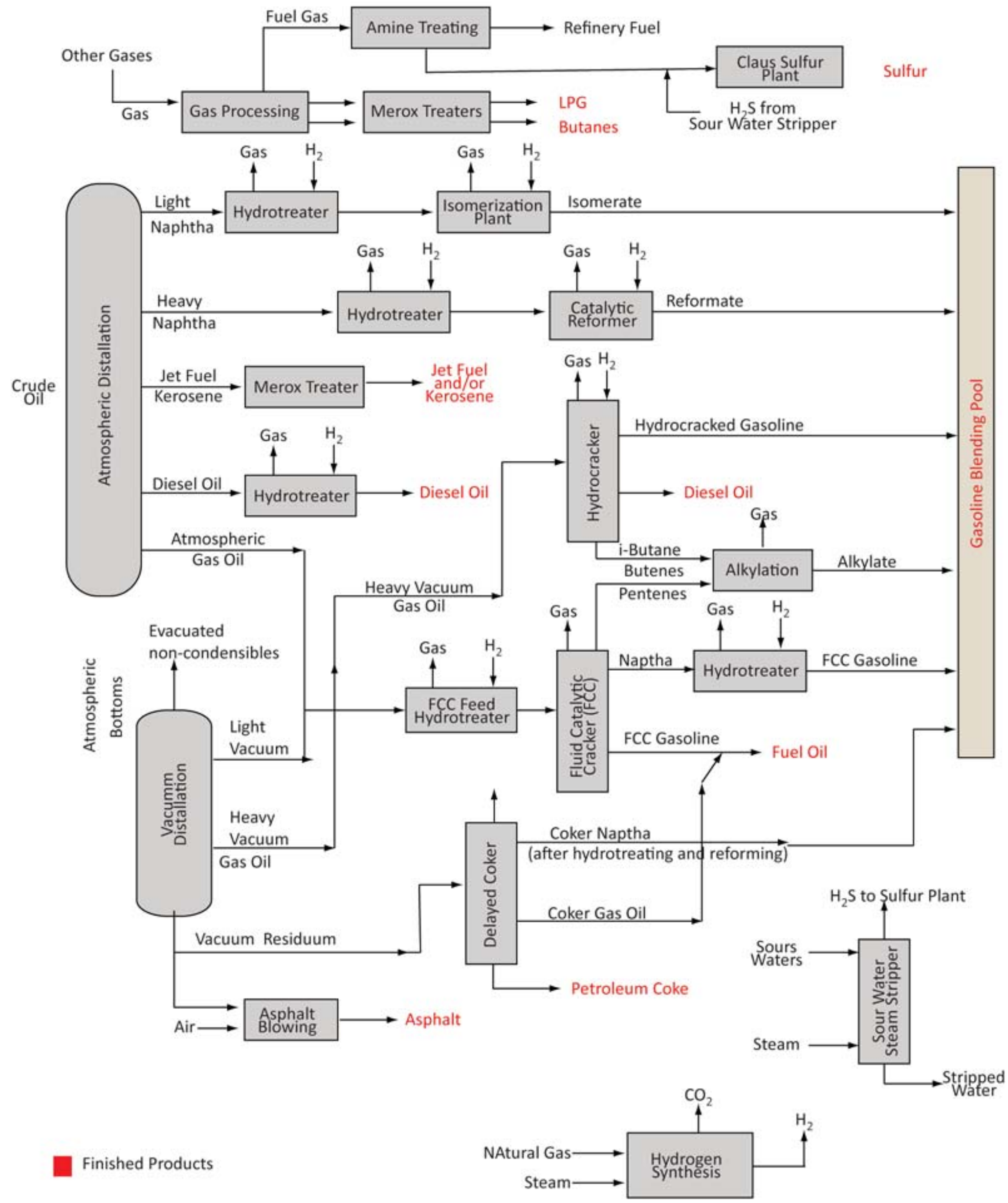


Figure 2.1
Crude oil refining process

Base Oil Categories

The American Petroleum Institute (API) developed a classification system for base oils that focuses on the paraffin and sulfur content and degree of saturation of the oil. The ***saturate level*** indicates the level of molecules completely saturated with hydrogen bonds, leaving them inherently unreactive. There are five groups in the classification system, ranging from Group I – Group V. Figure 2.2 details the five groups by their manufacturing

Base Oil Characteristics by Group

Defining Mineral Oil Properties

process, saturate and sulfur level and their viscosity index (VI). General group characteristics are listed below.

Base Oil Characteristics by Group

Group I Characteristics

Group I base oils are the least refined of all the groups. They are usually a mix of different hydrocarbon chains with little uniformity. While some automotive oils use these stocks, they are generally used in less-demanding applications.

Group II Characteristics

Group II base oils are common in mineral-based motor oils. They have fair-to-good performance in the areas of volatility, oxidation stability, wear prevention and flash/fire points. They have only fair performance in areas such as pour point and cold-crank viscosity.

Group III Characteristics

Group III base oils consist of reconstructed molecules that offer improved performance in a wide range of areas, as well as good molecular uniformity and stability. These synthesized materials can be used in the production of synthetic and semi-synthetic lubricants.

Group IV Characteristics

Group IV base oils are made from polyalphaolefins (PAO), which are chemically engineered synthesized base stocks. PAOs offer excellent stability, molecular uniformity and improved performance.

Group V Characteristics

Group V base oils are also chemically engineered stocks that do not fall into any of the categories previously mentioned. Typical examples of Group V stocks are esters, polyglycols and silicone. As with Group IV stocks, Group V stocks tend to offer performance advantages over Groups I – III. An example of a mineral-based Group V exception would be a white oil, a very pure lubricant used in industries ranging from cosmetics to food processing.

Defining Mineral Oil Properties

Mineral oils are generally classified as paraffinic and naphthenic. The difference between paraffinic stocks and naphthenic stocks is one of molecular composition, resulting in inherent solvent differences between the two types of stock.

Base Oil Categories

Group	Manufacturing Process	Saturate Level	Sulfur Level	Viscosity Index
Group I	Solvent Freezing	< 90%	> 0.03%	80 - 120
Group II	Hydroprocessing and Refining	≥ 90%	≤ 0.03%	80 - 120
Group III	Catalytic Dewaxing	> 90%	< 0.03%	> 120
Group IV	Chemical Reactions	All polyalphaolefins (PAOs)		
Group V	As Indicated	All others not included in Groups I, II, III, or IV		

Figure 2.2
Base Oil Categories

Section 2

Paraffinic Stock

Paraffinic oils are characterized by straight chains of hydrocarbons where the hydrogen and carbon atoms are connected in a long linear composition, similar to a chain.

The wax matter within the paraffinic stock results in these elements turning to solids at low temperatures; therefore, untreated paraffinic stocks do not have good cold-temperature performance and consequently, the pour point of paraffinic stocks is higher. For a paraffinic stock to flow at low temperatures, the heaviest waxes must be removed and usually pour-point depressants are necessary.

Paraffinic stocks display good high-temperature performance with high oxidation stability and high flash/fire points. Paraffinic stocks also have a high viscosity index (VI), meaning they exhibit high viscosity stability over a range of temperatures.

Naphthenic Stock

Naphthenic oil stocks are much like paraffinic stocks in that they contain only hydrocarbons. However, naphthenic stocks differ and are characterized by a high amount of ring hydrocarbons, where the hydrogen and carbon atoms are linked in a circular pattern. Conventionally, when the paraffinic carbon content of oil is less than 55 - 60 percent, the oil is labeled as naphthenic.

Naphthenic crudes contain very little to no wax and therefore will remain liquid at low temperatures; however, they thin considerably when heated. Naphthenic stocks generally have a low VI. These stocks have higher densities than paraffinic stocks, and they have greater solvency abilities than their paraffinic counterparts. Because naphthenic stocks contain little wax, they display lower pour points than paraffinic stocks. These stocks are also volatile and have a lower flash point.

Because naphthenic crudes contain degradation products that are soluble in oils, they present fewer problems with the formation of sludge and deposits. Due to the performance characteristics of naphthenic oils, they are generally used in applications where low pour points are required and the application temperature range is narrow.

Defining Synthetics

A true definition for the term ***synthetic oil*** has been difficult to reach, although it has generally been accepted that the term represents those lubricants that have been specifically manufactured for a high level of performance. Group III base oils with very high viscosity indices can be called synthetic oils in most countries.

The construction of a synthetic base stock varies depending on the particular stock. While mineral stocks are derived through a distillation process, synthesized stocks are derived from a chemical-reaction process. Synthetic lubricants are engineered for a specific molecular composition; they undergo a specific reaction process to create a base fluid with a tailored and uniform molecular structure. This allows chemists to develop lubricants with specific and predictable properties.

While an average mineral oil stock may possess a moderate amount of semi-beneficial molecular compounds, synthetic stocks, by design, can be composed completely of beneficial molecular compounds. Because of this, synthetic stocks are able to extend the service life of both oil and equipment, and they also have a wider range of acceptable temperature margins than conventional stocks.

Oftentimes people misunderstand the term *synthetic lubricant*, believing it refers to one type of stock, when it in fact represents a number of oil stocks. While it can be generalized that all synthetic lubricants have superior performance capabilities over mineral oils, the variations in characteristics can be significant. One synthetic stock can be excellent for the production of motor oils and drivetrain fluids, while others will be totally unacceptable for such applications.

The most common synthetic base stocks used in the transportation industry are PAOs, esters and Group III oils. Keep in mind that within each family name, additional groups may exist. For example, esters can be further divided into sub-categories of esters with varying properties.

Synthetic Hydrocarbons

Synthetic hydrocarbons are the fastest-growing synthetic lubricant base stock. ***Synthetic hydrocarbons*** are fluids that are formulated to specifically meet critical requirements and provide superior performance. These fluids often are made from a single type of molecule, usually of restricted molecular range. Such tailored fluids provide increased performance characteristics over petroleum stocks.

Synthetic hydrocarbon base stocks can be used in combination to provide characteristics such as solvency, temperature performance, surface strength and volatility qualities.

Polyalphaolefins (PAOs)

Of all the synthetic base materials, PAOs are likely the closest relative to mineral oil stocks. Both types of oil stocks are composed of similar hydrocarbon molecules; however, PAO stocks consist of a single molecular structure, whereas mineral oil contains a broad range of structures.

PAOs are commonly manufactured by reacting ethylene gas with a metallic catalyst. The major advantage of PAOs is their ability to function over a broader temperature range than their mineral-based counterparts. PAOs also provide good stability, which helps reduce engine deposits. Correctly formulated PAOs have the ability to hold large quantities of contaminants in suspension, further reducing deposits.

Group III Oils

Group III oils undergo the most stringent level of refining for petroleum oils; most of the waxes and impurities naturally occurring in the oil are removed. The high level of refining gives Group III oils a high level of performance – in some instances outperforming PAOs.

Lubrication Fundamentals: Section 3
The Physical Properties of Lubricants

Introduction
Section 3 discusses the physical properties of lubricants and how these properties affect the oil's ability to function properly. The physical properties of lubricants include: viscosity, temperature performance, shear stability, water resistance and volatility. These properties are inherent to lubricants but can be managed for optimal lubricant performance with appropriate base-stock formulations and additive packages.

Section Objectives

After studying Section 3, you should understand and be able to explain the following terms and concepts:

1. Viscosity and how it relates to lubricant performance
2. How low and high viscosity can influence a machine's efficiency
3. How an oil's viscosity affects its ability to withstand varied temperature, pressure and speed
4. The difference between Kinematic Viscosity and Absolute Viscosity
5. The effect of repeated heating and cooling cycles on an oil's viscosity
6. The benefits of a lower-viscosity oil on energy requirements
7. What causes shear force and how it affects oil's viscosity
8. The effect water can have on lubricants and component surfaces
9. How water contamination can lead to sludge formation
10. How the composition of AMSOIL lubricants provides greater stability over conventional lubricants
11. How flash and fire points provide clues to how a lubricant will perform in high-temperature applications

Section Keywords

The following keywords are defined in this section. Pay particular attention to their explanations as these concepts will serve as building blocks for future lessons.

Absolute Viscosity
Auto-Ignition Point
Dielectric Strength
Flash Point
Fire Point
Hydrolysis
Hydrolytic Stability
Kinematic Viscosity
Permanent Shear
Pour Point
Shear Point
Shear Stability
Stable Pour Point
Temporary Shear
Viscometer
Viscosity
Viscosity Index
Volatility
Water Resistance

Understanding Viscosity

Viscosity is the most important physical property of a lubricant. How the viscosity of a fluid reacts to changes in temperature, pressure or speed determines how well a fluid can perform the basic functions of a lubricant.

In basic terms, viscosity is the property that causes honey and water to flow differently when poured; they have different viscosities from each other. In specific terms, when external forces act on a fluid (such as gravity), the molecules within the fluid begin to move against each other, resulting in molecular friction that resists flow. ***Viscosity*** is a measure of that internal friction, or the measurement of a fluid's resistance to flow.

Viscosity is an important characteristic to consider when determining which fluid is most suitable for an application. If viscosity is too low, boundary friction between mating components generates heat and excessive wear. If the oil's viscosity is too high, it can cause excessive heat and increased energy consumption. For most applications, using a higher or lower viscosity grade fluid provides no additional benefit so long as it falls within the range required by the equipment manufacturer.

A lubricant's viscosity range is often reported by using a grading system such as those established by the Society of Automotive Engineers (SAE) or the International Organization for Standardization (ISO). Requirements for motor oils, both gasoline and diesel, have been set forth in the SAE J-300 Engine Oils Viscosity Classification and the American Petroleum Institute (API) Service Classification.

Knowing that a fluid's viscosity is directly related to its ability to carry a load, one would think that the more viscous a fluid, the better it is. However, the use of high-viscosity fluid can be just as detrimental as using an oil whose viscosity is too low. Lubricants with inadequate viscosity for the application may lead to:

- Increased metal-to-metal contact
- Increased friction and wear
- Increased oil consumption
- Leaking seals

Lubricants with too high a viscosity for the application could produce equally negative results, including:

- Increased fluid friction
- Increased operating temperatures
- Poor cold-temperature starting
- Reduced energy efficiency

The key is to select a fluid with a viscosity that is not too low or too high. The viscosity of an effective lubricant must be adequate to keep moving parts separate under normal operating temperatures, pressure and speed.

Temperature

Lubricant stocks thicken as they cool. As their temperature continues to drop, they eventually solidify. This thickening increases the lubricant's load-carrying abilities, but its ability circulate becomes significantly impaired. On the other hand, fluids thin when heated, decreasing their ability to carry a load and prevent metal-to-metal contact.

Pressure

As oil is subjected to extreme pressure, its viscosity usually increases. This increase in viscosity is directly related to its load-carrying capabilities; the greater a fluid's viscosity, the greater pressure or load it can withstand, allowing separation between moving parts to be maintained. But there are limits to this relationship. Extreme pressure and the viscosity increase it imparts can negatively affect an oil's pumpability. In a situation where oil cannot be pumped or circulated within a lubricating system, the oil is rendered useless.

Speed

Whether the application is a grease-filled bearing, a piston or an oil-filled gearbox, one must consider a lubricant's optimal viscosity based on the application's running speeds. As speed increases, components may require lower-viscosity oil to operate efficiently. Furthermore, high viscosity or speed may also increase the lubricant's film thickness, which increases fluid friction. If the viscosity is too high, fluid friction generates excessive heat that reduces the life of the lubricant.

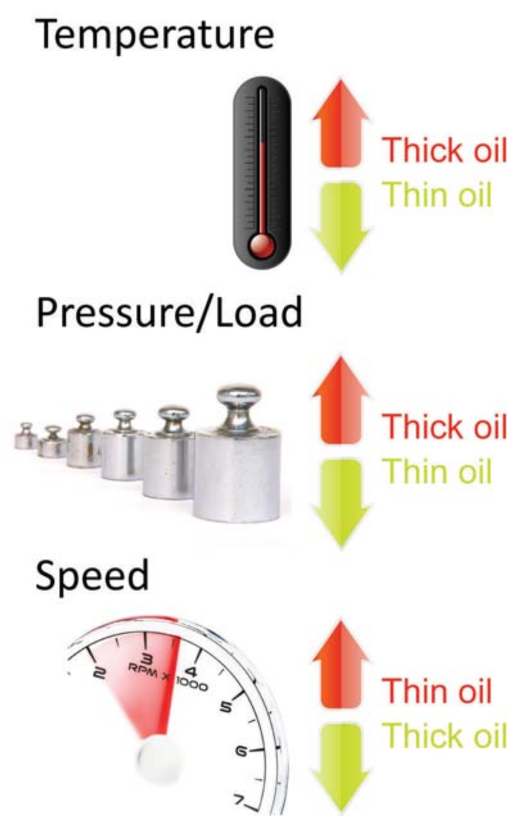


Figure 3.1
Speed, temperature and load affect oil viscosity requirements.

Viscosity Classification

Some of the more common terms used to describe the viscosity of a relatively free-flowing fluid, like water, include thin, light and low. Terms such as thick, heavy or high suggest a fluid with strong resistance to flow; like honey. However, these terms are general and difficult to measure. More specific classifications require a closer look at how fluids move.

Temperature affects how a fluid moves. Imagine how the viscosity of honey would greatly increase at temperatures near freezing and decrease near boiling temperatures. To understand these different reactions, viscosity types are scientifically classified as Kinematic Viscosity or Absolute Viscosity.

Kinematic Viscosity

Kinematic viscosity describes a fluid's visible tendency to flow. Think of this as the time it takes to watch a fluid pour out of a container. This tendency to flow is expressed in units suggesting the volume of flow over time, called centistokes (cSt).

Figure 3.2
Kinematic viscosity is a fluid's visible tendency to flow; water has a lower kinematic viscosity than honey, meaning it flows faster.

Kinematic Viscosity Test (ASTM D445)

Kinematic viscosity is commonly determined under high temperatures using the American Society for Testing and Materials (ASTM D445) Viscosity Test. This test uses a uniformly marked or calibrated tube called a ***viscometer*** and a heating bath. The temperature of the bath is set at either 104°F (40°C), which is typical for industrial lubricants like hydraulic fluids, compressor oils or gear lubricants, or 212°F (100°C), which is typical for motor oils. The test oil is placed in a viscometer and heated by the bath to the specified stable temperature.

When the specified temperature is reached, the oil is drawn into a wider area within the viscometer, which is identified by upper and lower marks, and allowed to drain out. The elapsed time can be directly converted into centistokes (cSt). To be relevant, the cSt number must be reported along with the temperature at which it was determined. It is important to note

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that when comparing fluid viscosities, fluids being compared must be tested at the same time and at constant temperatures, or the comparison is invalid.

Although centistokes are the most common unit of measurement when determining kinematic viscosity, results may also be reported in units known as Saybolt Universal Seconds (SUS or SSU). Even though identical test temperatures may have been used to determine the oil's viscosity in both centistokes and Saybolt Universal Seconds, the two should never be compared at face value because they are different units of measure. To do so would be similar to comparing distances in miles and kilometers. Viscosity reported in SUS is becoming increasingly rare.

Absolute Viscosity/Dynamic

Absolute viscosity, or dynamic viscosity, is a fluid's resistance to flow. Think of this as the energy required to move an object through a fluid. It takes little energy to stir water with a spoon; however, stirring honey with the same spoon requires significantly more energy. Absolute or dynamic viscosity is generally expressed in units known as centipoise (cP). As with cSt and SUS units, the higher the number of cP units assigned to a fluid, the greater its viscosity.

Figure 3.3
Viscometer device used to determine a liquid's absolute or kinematic viscosity.

Brookfield Viscosity Test for Cold Temperatures (ASTM D2983)

The Brookfield Viscosity Test is used to determine the internal fluid friction of a drivetrain lubricant at cold temperatures. A fluid sample is cooled in an air bath at -40°F (-40°C) for 16 hours. The sample is then carried in an insulated container to a nearby Brookfield viscometer, where the force required to move an object through oil is recorded and converted to centipoise. Lower cold-temperature viscosities (lower cP numbers) reported with this test indicate improved performance at cold temperatures.

Cold Crank Simulator Test for "W" Oils (ASTM D5293)

The Cold Crank Simulator (CCS) Viscosity Test is used to determine the internal fluid friction in motor oils with a "W" grade designation. This test is calculated in cP units as well, and measures the amount of energy required to overcome the resistance present in a lubricant that has been collected at temperatures from 23°F (-5° C) to as low as -31°F (-35°C), depending upon the anticipated SAE "W" classification of the oil being tested. Performance requirements to meet SAE "W" grades are outlined in the SAE J-300 engine oil viscosity classifications.

The CCS Viscosity Test simulates an engine's ability to turn over at cold temperatures. Gauges monitor rotations per minute (rpm), amperage draw and motor input. A universal motor is run at a constant voltage to drive a rotor, which is closely fitted inside a stator and immersed in the test oil.

The viscosity of the oil at the given test temperature determines the speed of the rotor and amperage draw; thicker oil results in slower speed and more amperage drawn. Speed and amperage drawn are then converted to centipoise.

Like the Brookfield Viscosity Test, CCS results showing a lower cP number indicate lower viscosity. Oils that are thicker at low temperatures (high cP number) tend to exhibit more resistance and require more energy to pump and circulate and display a higher cP number on the CSS test. A higher cP number at a given temperature is directly correlated to a greater amount of energy required to turn an engine over, and it also indicates a greater potential for starting difficulties. Most importantly, CCS results suggest a lubricant's ability to be circulated at a given temperature and its ability to provide wear protection.

Viscosity Index

The ***viscosity index*** (VI) of a lubricating fluid refers to how much the viscosity of the fluid changes due to temperature. A high VI indicates the fluid undergoes little viscosity change due to temperature fluctuations, while a low VI indicates a relatively large amount of viscosity change.

Fluids with a high VI provide more protection to critical components over a wide range of temperatures by maintaining fluid thickness and the necessary fluid barrier between parts.

Viscosity Index Test (ASTM D2270)

The Viscosity Index Test (ASTM D2270) is based on the kinematic viscosity of the fluid at 104°F (40°C) and 212°F (100°C). Fluids whose viscosities do not change much between these two temperatures will have higher viscosity indices than those whose viscosity changes are greater. Viscosity index numbers above 95 are considered high.

AMSOIL Advantage

Thermal Stability

AMSOIL synthetic base oils have better thermal stability than mineral oils. Thermal stability permits the oils to be used longer, even as speeds and temperatures increase. It also allows oils to retain their viscosities at low temperatures. Lower-viscosity oil provides better cold-weather operation, allowing the oil to be quickly circulated at cold-temperature startups and supply engine components with the proper lubrication to keep them protected.

High Viscosity Index

AMSOIL lubricants are formulated to have naturally high viscosity indices, so the need for viscosity index improvers is reduced. The VI improvers used in AMSOIL lubricants are temperature specific, meaning they are activated only when certain temperature requirements are met. In most cases, VI improvers help maintain thickness at higher temperatures while having minimal effect at low temperatures. By using viscosity improvers with a high shear-stability index, AMSOIL is able to achieve optimal cold-weather performance with virtually no loss to shear-stability performance.

AMSOIL lubricants resist thinning at high temperatures (high VI) and can suppress the generation of additional friction and heat generated by components in contact due to a thinning lubricant.
AMSOIL Synthetic Heavy-Duty Diesel Oil (ACD) and Synthetic Small

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Engine Oil (ASE) meet multi-grade viscosity requirements without the use of viscosity modifiers because their synthetic base oils have naturally high viscosity indices and are wax-free. These oils meet both the low-temperature requirements of SAE 10W and the high-temperature requirements of SAE 30, allowing the oil to perform adequately at both hot and cold temperature extremes.

Understanding Pour Points

Effective lubricants must be able to function at all of the varied temperatures in which the equipment they lubricate may be used. One key measure of lubricant quality is its ability to flow at low temperatures.

Pour point is the physical measurement of oil's fluidity at cold temperatures and refers to the lowest temperature at which oil maintains its ability to flow. Oils thicken as they cool and will solidify in extreme cold.

While this reaction to cold is characteristic of most fluids, those that contain paraffinic material (wax) common in petroleum stocks are more significantly affected by low temperatures. These waxes can cluster, or agglomerate, as oil is cooled, warmed and cooled again, raising the pour point over repeated cycles. For example, paraffinic oil that had an original pour point of -5°F (-20.5°C) may increase to +10°F when exposed to repeated cycles of warming and cooling. The pour point of paraffinic base oil can be enhanced through the use of pour-point depressants. Synthetic stocks such as PAOs and esters are free of paraffinic contaminants.

Figure 3.5
A lubricant's pour point is a key measure of its ability to flow at low temperatures.

Pour point can provide insight into an oil's ability to properly lubricate at low temperatures; however, pour point does not ensure usability at such temperatures. A fluid's pour point does not indicate its lowest possible functional temperature. The usable low temperature of oil, called its ***stable pour point***, is typically 5°F to 15°F above its indicated pour point. A fluid's stable pour point is of even greater significance as it is a better indicator of low-temperature performance and protection. If oil is unable to flow, its pumpability is questionable. The inability to circulate oil results in accelerated wear and possible engine damage. Up to 60 percent of total engine wear occurs during cold-starting conditions, before oil can be circulated throughout the engine. Minimizing this delay significantly reduces the potential for wear and helps prolong engine life.

While the CCS test measures startability, borderline pumping temperature is used to determine an oil's ability circulate through the lubrication system – its pumpability. The equipment used in this test is typically referred to as a mini-rotor viscometer. This test apparatus is capable of measuring oil's borderline pumping temperature between 32°F and -40°F only (0°C and -40°C). A sample is exposed to repeated heating and cooling cycles to simulate use in cold climates. Used exclusively for motor oils, this test procedure is required for all oils with an SAE "W" rating.

Standard Pour Point Test (ASTM D97)

The most common method for determining the pour point of oil is the Standard Pour Point Test (ASTM D97). In this test, an apparatus cools an oil sample to determine its pour point. A vial is filled with a specific amount of test oil and then placed into the bath to cool. After every 5°F drop in temperature, the vial is removed and tilted. If the oil moves (flows) off of a specified fill line within five seconds, it is cooled another 5°F. The test temperature continues to decrease until no flow occurs within the five-second tilting periods, or until -76°F (-60°C) is reached (the lowest testing limit of the cooling bath). This temperature is then recorded and +5°F is added. This new temperature is reported as the oil's pour point.

While certain regions may never have to contend with extremely cold temperatures, it should be noted that lubricants with lower pour points may also aid in increased fuel economy, energy efficiency and ease of starting.

AMSOIL Advantage

Superior Pour Point
AMSOIL synthetic lubricants have inherently low pour points. Such cold-temperature performance allows the oil to circulate in a lubrication system easily at frigid temperatures. Being able to circulate at such temperatures means that engine components are protected during cold starts; typical mineral oils exhibit a delay in their ability to circulate and expose components to metal-to-metal contact, increasing wear and reducing engine life. A lubricant that can be poured at low temperatures also provides fuel efficiency benefits to automobiles. The low viscosity of these lubricants reduces drag on engine components, allowing them to move more efficiently.

Understanding Shear Stability

For any lubricant to be useful it must remain stable while in use. For example, if equipment requires a specific viscosity for effective operation, the ability of a lubricant to retain its designed viscosity is one measure of stability. One of the elements that can break this stability is the natural stress or shear that occurs within a fluid during use. Lubricants must retain shear stability to remain effective at lubricating and protecting equipment.

Shear stability refers to a lubricant's ability to resist shear. Generally, ***shear*** occurs when one layer of a fluid begins to move in a direction different from another layer of that same fluid. For example, where two components are separated by a lubricant, such as a piston and cylinder wall, some of the lubricant film would naturally move in the direction of the piston. The lubricant layer in contact with the cylinder would begin

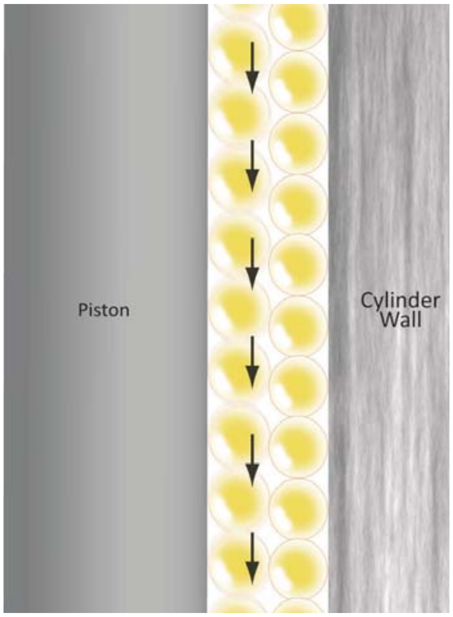

Figure 3.6
Shear results when one layer of fluid moves in a direction different from another layer of that same fluid.

to shear away from the lubricant layer in contact with the piston. This is known as the shear point. This resulting shear can reduce lubricant viscosity; loss of fluid viscosity can occur from conditions known as temporary or permanent shear.

Temporary shear occurs when long viscosity index improver molecules align themselves in the direction of the stress or flow. This alignment generates less resistance and allows for a reduction in fluid viscosity. Yet, when the stress is removed, the molecules return to their random arrangement and the temporary loss in viscosity is recovered.

Permanent shear occurs when shear stress ruptures long molecules and converts them into shorter, lower-weight molecules. The shortened, lighter molecules offer less resistance to flow, which minimizes their ability to maintain viscosity.

Mechanical activity within an engine creates shearing forces that can negatively affect a lubricant's protective viscosity. Even lubricants that provide consistent viscosity through a wide temperature range (a high viscosity index) are susceptible to shearing forces that reduce viscosity and load-carrying ability. Engines operating at high rpm and those that share a common oil sump with the transmission, like many motorcycles, experience high shear rates.

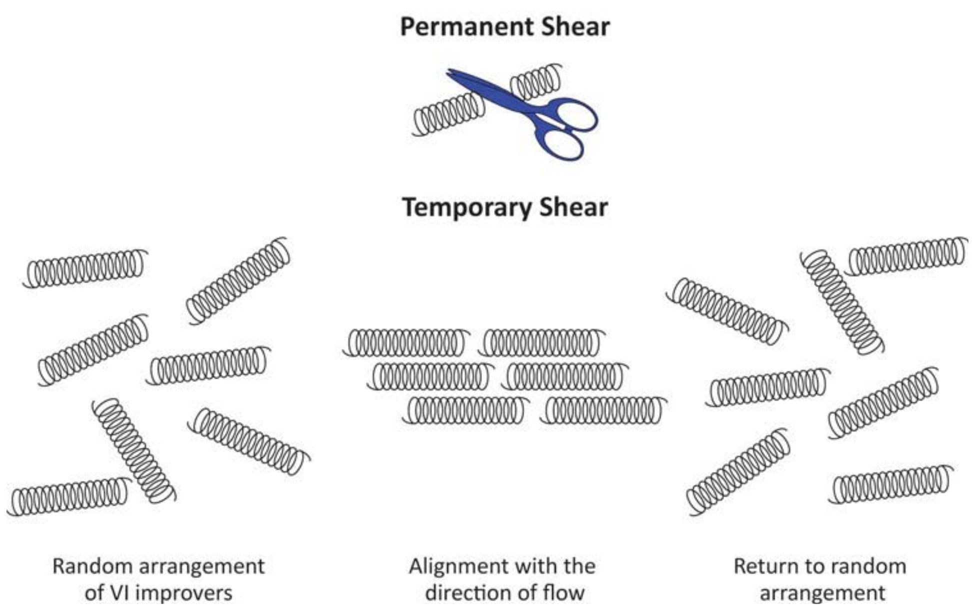

Figure 3.7
Viscosity Index improvers can be subject to shear in service. Permanent shear occurs when long molecules rupture, while temporary shear occurs when molecules align themselves in the direction of flow or stress.

Viscosity Index improvers used in multi-viscosity oils can shear back when subjected to the combination of high operating temperatures and shearing actions found in modern engines. Permanent shearing of VI improvers can result in piston-ring sticking (due to deposit formation), increased oil consumption and accelerated equipment wear. Some VI improvers are significantly more shear stable than others. Although the type of base stock used and the intended application determines the need for VI improvers, many synthetic stocks may not require them at all.

Because VI improvers can be subject to shear conditions, formulating an oil using little or no VI improvers can be advantageous. In addition to the problems caused by shear stability, VI improvers' quality varies dramatically and cannot always be easily determined.

When comparing oils, small differences in shear stability indicate a significant drop in performance. AMSOIL Synthetic Motorcycle Oil is absolutely shear stable and will not thin from mechanical activity, indicating it is an excellent choice for bikers who demand the best lubrication for their motorcycles.

High-Temperature/High-Shear Test (ASTM D5481)

The High-Temperature/High-Shear Test (ASTM D5481) simulates shearing conditions at elevated temperatures. The viscosity of the oil is measured at 302°F (150°C) under shearing forces, and results are reported in centipoise (cP). The higher the test result, the greater the level of protection offered by the oil. A temperature of 302°F (150°C) is necessary because bearings and other components require the greatest protection during high-temperature operation.

The Viscosity Shear Stability Test (ASTM D6278)

The Viscosity Shear Stability Test (ASTM D6278) determines a lubricant's shear stability. After measuring its initial viscosity, the oil is subjected to shearing forces in 30-cycle intervals. Viscosity is measured and compared to the oil's initial viscosity following 30, 90 and 120 cycles. The lower the degree of change, the better protection the lubricant provides against shearing forces.

AMSOIL Advantage

Stable Viscosity

AMSOIL synthetic lubricants maintain viscosity under extreme temperature fluctuations and shearing forces; they meet requirements set forth for multi-viscosity oils requiring a minimum oil viscosity. Whereas some conventional mineral oils degrade when exposed to high temperatures and high forces, AMSOIL synthetic lubricants offer superior wear protection in extreme temperatures.

AMSOIL synthetic lubricants are inherently better at maintaining viscosity over a wide temperature range (high VI), and, coupled with shear-stable VI improvers, they maintain viscosity characteristics better at high temperatures and for longer durations than conventional oils.

Understanding Water Resistance

Water is the most common contaminant and a primary cause of breakdown in lubricating oils. It can contaminate lubricants as they leave the controlled environment of the blending facility before they reach the consumer or equipment. Contamination can also occur during bulk transportation when a product is transferred from different storage containers. For example, when oil is transferred from a rail car to a storage tank or delivery truck.

Water contamination can also be caused by condensation, which is more prevalent in climates where temperature extremes cause increased condensation and water formation in the oil sump. It can also be caused by radiator or transmission cooler leaks, defective seals, blown or cracked gaskets or from the environment in which a lubricant is used, like in steam turbine oils and marine applications.

What is Water Resistance?

Water resistance is a lubricant's ability to resist the process of ***hydrolysis***, or the chemical reaction in which a chemical compound, like oil, is broken down by reaction with water. When a lubricant successfully resists hydrolysis it achieves ***hydrolytic stability***.

As air or other gases are compressed, moisture from humidity condenses and collects in the oil, creating the need for oils with good hydrolytic stability. Good hydrolytic stability is important in many lubricant applications because it helps prevent oil degeneration. These reactions can form acids, foaming and insoluble contaminants that change viscosity, cause corrosion and reduce lubricant performance.

Hydrolytic Stability Test (ASTM D2619)

The Hydrolytic Stability Test (ASTM D2619) determines the stability of oils in contact with water and metal catalysts. Fluids that are unstable to water under conditions of the test form corrosive acidic and insoluble contaminants. Seventy-five grams of fluid, 25g of water and a polished copper strip are sealed in a bottle, then placed in a 200°F (93.3°C) oven and rotated end over end at five rpm for 48 hours.

Upon completion of the test, four important results are evaluated and reported:

1. Acidity of water layer
2. Appearance of the copper panel
3. Weight change of copper panel
4. Percent change in oil viscosity

The appearance and weight of the copper panel indicate the effects of corrosion. Acidic air compressor oil with an unstable viscosity can corrode internal parts and shorten oil life. Because acid increase in the water layer can affect the acidity of the oil, lower acidity of the water is desirable.

Water contamination is the primary cause of lubricant breakdown. It causes chemical breakdown of base oils and additives, corrodes component surfaces and accelerates wear due to reduced lubricant film strength. Glycol and other additives found in common antifreeze packages can thicken oil and enhance sludge formation in addition to reducing lubricity. As a result, water intrusion from antifreeze can cause significant engine damage.

AMSOIL Advantage

High Hydrolytic Stability
AMSOIL lubricants display high hydrolytic stability. Under the most demanding conditions, they form very little acid and insoluble contaminants. This helps reduce acid formation, foaming and contaminant formation, ensuring the lubricant is acceptable for long-term use.

If demulsifying oils lose their ability to easily separate from water, oxidation is encouraged (this concept is discussed more in the Managing Water discussion in Section 4). Although a little oxidation will not necessarily limit the oil's life, it will begin to reduce the oil's ability to separate from water that may be present. As a result, persistent undesirable emulsions may be formed. Persistent emulsions are prone to join with insoluble oxidation products like dirt to form sludge. Accumulations of sludge in oil pipes, passages and coolers may impair the circulation of oil and cause high oil and bearing temperatures. Sludge also may have detrimental effects on governor pilot valves and oil relays, causing sluggish operation, valve sticking or failure.

Water Content Tests

Four common tests can determine water content in engine oils: the Calcium Hydride Test, FTIR Spectrum Match Test, Crackle Test and Coulometric Titration Test (ASTM D6304). The Coulometric Titration Test produces the most accurate information and is commonly run after a positive finding by either the FTIR Spectrum Match Test or Crackle Test.

Calcium Hydride Test

The Calcium Hydride test is commonly used in the field. Solid calcium hydride is used as a reagent for water content of the oil. When water reacts with the calcium hydride, hydrogen gas is produced. The amount of hygrogen gas produced is directly proportional to the water content in the oil.

FTIR Spectrum Match Test

The FTIR Spectrum Match test is performed through computer analysis of an oil sample and requires a trained operator to interpret results.

Visual Crackle Test

A Visual Crackle Test provides a simple field method to detect and roughly measure the presence of water in engine lubricants. The test is a simple way to identify the presence of free and emulsified water in oil.

In this test, a hot plate is heated to 300°F (149°C). Once a constant temperature is reached, an oil sample is shaken vigorously to achieve a homogenous suspension of water in oil. Then, using a clean dropper, one drop of oil is placed on the hot plate. If the oil sample contains water, the response will occur immediately. The degree of the bubbling is directly proportional to the amount of water in the oil sample.

- If no crackling or vapor bubbles are produced after a few seconds: no free or emulsified water is present.

- If very small bubbles (0.5 mm) are produced but disappear quickly: approximately 0.05% - 0.1% water is present.
- If bubbles that are approximately 2 mm in diameter form, gather to the center of oil spot, enlarge to about 4 mm and then disappear: approximately 0.1% - 0.2% water is present.

Coulometric Titration Test (ASTM D6304) (Karl Fischer)

If the Visual Crackle Test indicates water is present in a lubricant, a laboratory can perform the Coulometric Titration Test (ASTM D6304) to provide a more accurate assessment of total water content. The Coulometric method is used for low moisture levels in the range of 10 micrograms to 10 milligrams of water contamination.

Understanding Electrical Resistance

Oil used in applications where electrical conductivity is an issue must be checked to determine resistance to electricity. Users of equipment such as boom trucks for electric or telephone companies frequently need to determine the dielectric strength of a lubricant for safety reasons.

Dielectric strength is the measure of the lubricant's resistance to electrical flow. Lubricants with high dielectric strength insulate better. The unit of measure for dielectric strength is the kilovolt (kV).

Electrical conductivity of oil is important in equipment subjected to stray or self-generated electrical currents. The dielectric strength of lubricating oils can vary significantly depending on the base oil used and the oil's additive composition. It is also affected by contamination from water, wear metals, decomposition or combustion products.

Most applications that require dielectric strength call for a rating of 25 or 30 kV. AMSOIL hydraulic oils easily exceed these levels and are safe for use in such applications. Be sure to verify the equipment manufacturer's requirements if dielectric strength is a concern.

Dielectric Breakdown Test (ASTM D4308)

The standard method for determining conductivity is called a Dielectric Breakdown Test (ASTM D4308). In this test, a disk electrode system uses 25-mm diameter square-edged disks separated by 2.5 mm. A cell of these disks is filled with oil to cover the electrodes to a depth of at least 20 mm, and the sample is allowed to set for at least two minutes without agitation. A 60 Hz variable current of voltage is applied at an increasing rate of 3000 V until breakdown occurs as indicated by passage of a current through the sample of 2 to 20 milliamps (mA). The transfer of current is used to trip a relay within three to five cycles that stops the voltage ramping, maintaining the breakdown voltage. A series of determinations are done, which are then treated statistically to yield the final result.

Understanding Volatility

Volatility is the property that defines a lubricant's evaporative loss. The more volatile a lubricant is, the lower the temperature at which the lubricant will begin to evaporate. The more it evaporates, the less oil is left to protect equipment and the faster a user must replace the lost oil.

The small, light molecules in conventional lubricants evaporate at relatively low temperatures. These light molecules require less energy in the form of heat than heavier molecules to be lifted out of the solution and into the air. The tendency of a liquid to evaporate is referred to as ***volatility***.

Why is Volatility Important?

Volatility is a common phenomenon and many drivers have experienced its effects by owning an automobile that "uses" motor oil in irregular intervals. Some vehicles seem to use oil rapidly soon after an oil change, but will stabilize after a short time when make-up oil is added. This is caused by the lighter elements evaporating out of the solution, causing the oil level to drop after the initial oil change. Adding oil to replace this loss leads to stabilization as the majority of light elements are now gone.

Volatility affects more than the rate of oil consumption. When light elements in oil evaporate from heat, the oil's viscosity increases. This thicker oil forces the engine to work harder, resulting in several problems, including:

- Performance loss
- Fuel-economy loss
- Poor cold-temperature starting
- Increased engine deposits

Because volatility causes oils to thicken with use, oil becomes harder to pump. Pumps that must move thicker oil wear more quickly and consume more energy. Parts require more energy to move through thicker oil than they do in thinner oil. As a result, extra energy is spent on pumping and moving through thick oil, reducing performance and fuel economy.

NOACK Volatility Test (ASTM D5800)

The most common method used in measuring oil volatility is the NOACK Volatility Test. In this test, an oil sample is weighed and then heated to a temperature of 482°F (250°C) for one hour. During this time, dry air is passed over the sample, which carries off the oil vapors that have boiled off and deposits them in a beaker attached to the apparatus. Finally, the original sample is removed and re-weighed. Any reduction in weight is reported as a percentage lost of the original weight. The entire procedure is very similar to the operation of a petroleum fractioning tower or still.

Currently, API SN and ILSAC GF-5 performance classifications require weight lost due to volatility to be no greater than 15 percent for all viscosity grades of motor oil.

AMSOIL Advantage

Less Volatility
AMSOIL synthetic lubricants are engineered to have uniform molecular shapes and weights. The advantage to this homogeneous composition is that there are less 'light fractions' that are susceptible to evaporation. AMSOIL synthetic lubricants are more stable than conventional motor oils for improved resistance to burn-off.

Understanding Flash and Fire Points

Flash and fire points help describe a lubricant's high-temperature performance and stability.

The ***flash point*** is the lowest temperature at which the vapor above an oil sample ignites when a flame is passed over it. Once the flame on the surface of the oil continues to burn for at least five seconds after the ignition flame has been removed, the temperature is recorded as the oil's ***fire point***. Fire points are generally higher than flash points by 10°F to 40°F. An additional classification, the ***auto-ignition point***, is the temperature at which oil will ignite on its own without the aid of an outside ignition source.

It's important to note that flash and fire points should not be used to ascertain oil's usable temperature range. This range is typically 100°F to 150°F (37.8°C to 65.5°C) lower than reported flash and fire point values.

Flash and fire points can be significantly different between lubricants. Some lubricants have a relatively small temperature range between flash, fire and auto-ignition points, while others have a significantly larger range. Oils that are more stable tend to have flash and fire points that are higher and closer together than oils that are more volatile.

Conventional lubricants often contain chemicals that break down at normal operating temperatures. The presence of oxygen increases the likelihood of breakdown of these chemicals, and oxygen can be found in almost all vehicle and equipment systems.

Ignition limits help aid in understanding what happens when a lubricant begins to break down from excessive heat. When contaminants in conventional oils break down, they deposit sludge and varnish on component surfaces, which leaves the oil thick and hard to pump. Oil that has broken down also has little heat-transfer capability.

High flash and fire points tend to suggest improved high-temperature stability, which reduces oil consumption and increases the oil's service life.

The Cleveland Open Cup Test (ASTM D92)

The Cleveland Open Cup Test (ASTM D92) measures flash and fire points of an oil. This test is intended for fluids having a flash point of 175°F (79.4°C) and above. A fixed volume of fluid is heated at a uniform rate while open to the atmosphere at its surface. A small flame is passed over the surface at uniform temperature increments to determine the point at which vapors ignite. This temperature is recorded as the oil's flash point. At a somewhat higher temperature, self-sustained burning for at least five seconds determines the fire point.

AMSOIL Advantage

High Flash and Fire Points

AMSOIL synthetic lubricants display high flash and fire points, meaning they are highly resistant to breakdown at normal operating temperatures. They offer more protection than conventional oils because they resist oxidation and thermal breakdown, retaining their pumpability and heat-transfer abilities.

Lubrication Fundamentals: Section 4
The Chemical Properties of Additives

Section 4 discusses the chemical properties of additives and how these properties affect an oil's ability to function as a lubricant, such as its ability to reduce friction, clean and reduce oil degradation. A discussion of how AMSOIL formulates base oils and additive packages to address these chemical reactions is included.

Section Objectives

After studying Section 4, you should understand and be able to explain the following terms and concepts:

1. Oxidation reactions
2. The importance of oxidation resistance
3. AMSOIL lubricants' resistance to oxidation
4. Extreme-pressure applications
5. The importance of resisting wear
6. The affect of foam on lubricant performance
7. The affect of water on lubricant performance
8. The four ways in which lubrication systems can become contaminated
9. How TBN affects its ability to handle contaminants

Section Keywords

The following keywords are defined in this section. Pay particular attention to their explanations as these concepts will serve as building blocks for future lessons.

Additives
Anti-Wear Additives
Condemning Limit
Demulsify
Demulsibility
Detergents
Dispersants
Emulsify
Emulsion
Entrainment
Extreme-Pressure Agents
Film Strength
Foam
Hydrolytic Stability
Metal Passivators
Oxidation
Sacrificial
Thermal Runaway
Total Acid Number (TAN)
Total Base Number (TBN)

The Chemical Properties of Additives

An understanding of how chemical additives enhance lubricants is necessary to make the proper recommendations for different applications.

In short, ***additives*** enhance lubricant functioning by performing two critical functions: they lessen destructive processes and enhance beneficial properties of the base oil.

Oil additives have had a significant affect on modern transportation and industrial processes. The use of sophisticated additives has allowed equipment to evolve into what it is today; enhancing performance capabilities by providing added efficiency and protection to internal systems.

Although there may be a variety of additives directed toward a specific function, such as to impart controlled frictional properties, the performance of each can differ significantly. The concentration at which an additive is used also has a major affect on how well a lubricant performs a given task. To achieve the proper mix of additive and base oil chemistries, an understanding of how different additives interact is necessary.

Additives can function to lessen the damage caused from oxidation, extreme pressure, wear, rust and corrosion. Additives can also enhance a lubricant's ability to control foam, separate or combine with water and keep the engine clean.

Resisting Oxidation

Oxidation and heat are the primary enemies of lubricant base stocks, especially conventional petroleum base stocks. Once oxidation and heat cause a lubricant to break down, it must be replaced or the resulting contamination and lack of lubrication will cause equipment damage.

Some of the chemicals in conventional lubricants break down at temperatures within the normal operating range of vehicle and equipment components. Some tend to break down and generate contaminants in relatively mild temperatures when exposed to oxygen, which is almost always present. These unstable contaminants do not help the lubrication process in any way, and chemical additives are necessary to keep the lubricant's performance in check under these oxidative conditions.

What is Oxidation?

Oxidation is the breakdown of lubricant base stock molecules as they chemically react with air in high-temperature environments. As the oil reacts with the air, it results in a permanent chemical change where oil molecules lose one or more electrons.

Oxidation increases exponentially as temperatures increase. For example, every 18˚F (10° C) increase in temperature doubles the rate of oxidation. Large amounts of entrained air, also known as foaming, and exposure to contaminants like water or acids increase the oxidation rate. Certain metals and acids can also act as oxidation accelerants.

The Importance of Oxidation Resistance

Oxidation can increase viscosity, acid content, sludge and other deposits while simultaneously depleting additives. In combination, these processes lessen a lubricant's useful operating life. Deposits such as varnish and lacquer form on hot metal surfaces that can further oxidize to form sludge and carbon deposits.

Since oxidation produces acids, measuring the acid components in a lubricant is an indirect way of determining the occurrence of oxidation. This measure is known as the ***Total Acid Number (TAN)***. In non-engine lubricants, TAN can help measure the extent of oxidation, which in turn can help determine if the oil is suitable for continued use. TAN values can be determined through conventional oil analysis.

When a lubricant reaches the end of its service life, it reaches its ***condemning limit*** and must be replaced. Depending on the application, a TAN between 2 and 5 typically indicates the lubricant has reached its condemning limit; however, TAN and condemning limits vary between application and product types.

Although oxidation resistance varies between different base stocks, most require the assistance of oxidation inhibitors to combat the negative results of oxidation and improve the life expectancy of a lubricant. A typical oxidation inhibitor is zinc dialkyldithiophosphate, more commonly referred to as ZDDP.

Oxidation Testing

AMSOIL uses several tests to evaluate the oxidation characteristics of its lubricants:

- Turbine Oil Oxidation Stability Test (TOST) (ASTM D943)
- 1000-Hour Sludge Test (ASTM D4310)
- Panel Coker Test
- Rotary Bomb/Pressure Vessel Oxidation Test (RBOT/RPVOT) (ASTM D2272)
- Thin-Film Oxygen Uptake Test/TFOUT (ASTM D4742)

Each of these tests has its own procedures, but all evaluate oxidation. The Thin-Film Oxygen Uptake Test (TFOUT) evaluates a lubricant's ability to resist heat and oxygen breakdown when contaminated with oxidized or nitrated fuel, or water and soluble metals such as lead, copper, iron, manganese and silicon. Designed to mimic the operating conditions of a gasoline engine, this test demonstrates the consistently superior oxidation stability of AMSOIL lubricants.

Thin-Film Oxygen Uptake Test (ASTM D4742)

During the test, the test oil is mixed with other typical chemistries that are found in gasoline engines. The test is conducted under high pressure at a high temperature of 320°F (160°C). The mixture is pressurized along with oxygen and other metal catalysts, fuel and water to simulate the operating conditions of the gasoline engine.

The breakdown of the oil's antioxidants is detected by a decrease in oxygen pressure, which is referred to as the induction time (break point) of the oil, which is recorded.

AMSOIL Advantage

Saturated Molecular Structure

AMSOIL synthetic lubricants are formulated with base oils that have a saturated molecular structure, meaning oxygen is prevented from attaching. This provides inherent heat and oxidation stability over conventional oils that are unsaturated. Because AMSOIL synthetic oils do not contain contaminants like conventional mineral oils, their base composition does not accelerate oxidation.

AMSOIL synthetic lubricants contain oxidation inhibitors that are far better than conventional oils. Oxidation inhibitors are ***sacrificial*** in nature, meaning they deplete, or are used over time. Since AMSOIL base oils have better oxidation stability on their own, oxidation inhibitors in AMSOIL synthetic oils last longer because they are not depleted as rapidly. AMSOIL uses a combination of oxidation-inhibitor systems for different temperatures and application needs.

Resisting Extreme Pressure

Certain applications, like differentials and transmissions, require lubricants to function effectively in extreme-pressure environments. In these environments extreme pressure can cause the lubricant film to thin so significantly it can no longer separate components. This boundary-lubrication condition can be mitigated by additives that protect components from damage and wear.

Extreme-Pressure Agents

Extreme-pressure agents are chemical additives that prevent sliding metal surfaces from seizing under extreme pressure. They work by providing a sacrificial wear surface or by changing the surface metallurgy of shock-loaded components (components exposed to heavy loads and significant shock, or impact). These additives usually contain sulfur, phosphorus or boron compounds and are activated at higher temperatures. Sulfur-containing additives possess excellent EP characteristics because sulfur forms a hard, sacrificial film on components. As contact takes place, it occurs between the films of sulfur rather than the component surfaces.

Figure 4.1
The ring-and-pinion gear in automotive differentials operates under extreme sliding and loading conditions that require EP agents for added protection.

Certain chlorinated compounds, such as chlorinated waxes, may also serve as EP additives, although currently, environmental and corrosion concerns limit their use for this application.

EP agents provide wear protection when the oil film fails to prevent contact between components, which is typically the case in boundary lubrication. The correct formulation of EP lubricants is very important; if

Section 4

the formulation is not precisely balanced, the EP additives can promote corrosion of copper, bronze or brass-containing components at high temperatures. EP additives can also sacrifice the thermal stability of the base oil. Proper formulation requires recognizing the trade-off between yellow-metal corrosion, thermal stability and EP protection.

Four-Ball EP Test (ASTM D2596)

One of the most common tests of a lubricant's performance under extreme pressure is the Four-Ball EP Test (ASTM D2596, 2783). The Four-Ball EP Test evaluates the extreme-pressure, anti-wear and anti-weld properties of lubricants. The Four-Ball EP test measures lubricant protection under high pressures and moderate sliding velocities. Pressure as high as 1 million psi inch can be attained on the four-ball EP test machine.

Figure 4.2
Example of welded test balls

During the test, three standardized steel balls are clamped together and submerged in the test oil. A fourth identical ball is then rotated in the junction area with the other three, making pinpoint contact with each and producing a wear spot at the contact site. Pressure is applied until a ball reaches its weld point and seizes or until extreme scoring occurs.

FZG Four-Square Gear Test

The FZG Four-Square Gear Test is used to develop and evaluate industrial gear lubricants, automatic transmission fluids and hydraulic fluids to meet manufacturers' specifications. Developed by the Machine Elements Gear Research Centre in the Technical University of Munich, this test consists of running the sample with 13 increasing load stages until failure. The damaged load stage is determined by a visual inspection that looks for more than 20 percent scuffing on the pinion gear, and a physical inspection that measures the combined weight loss of the drive wheel and pinion gear. In all of these tests, AMSOIL synthetic lubricants meet or exceed the American Gear Manufacturers Association (AGMA) minimum limits.

AMSOIL Advantage

Advanced Additive Packages

AMSOIL exceeds industry specifications by incorporating precise amounts of the best additives into lubricants for superior performance benefits. For example, AMSOIL uses organic compounds called metal passivators to protect yellow metals like copper and brass from corrosion.

AMSOIL uses heat-resistant additives to prevent lubricant breakdown in order to maximize the oil's service life. This approach of perfectly balancing protection and performance ensures that AMSOIL lubricants fully guard equipment during extreme-pressure operations.

Resisting Wear

Whenever a component moves against each other, wear will result, causing a change in the geometry of the component contact points as surface material is rubbed away. The wear causes scarring and abrasion to surfaces that impairs proper function. Wearing of components also introduces metal into the lubricant, where contamination can act as a catalyst to oxidation.

One of the most important functions of any oil is wear protection, which is critical for consumer value. Wear increases friction and causes energy loss in the form of equipment-damaging heat. Anti-wear agents reduce metal-to-metal contact, reducing friction and lowering operating temperatures, all of which can extend lubricant and equipment life.

Anti-Wear Agents

Like EP additives, anti-wear additives react chemically with metal surfaces to help form thin, tenacious films on loaded parts to prevent metal-to-metal contact. These additives assist in the reduction of friction, wear, scuffing and scoring under mild boundary lubrication conditions. Typical anti-wear additives include ZDDP and polar molecules, such as fatty oils, acids and esters. Rubbing contact activates these additives at low temperatures.

A common belief is that the higher the level of zinc additive found in a lubricant, the greater the oil's ability to minimize wear. Although this statement is partly true, zinc content does not always dictate wear performance. The mere presence of zinc does not mean it's in a form for effective anti-wear properties, such as ZDDP. Also, finding the right mix of the best additives is a subtle art. Unlike zinc, which readily shows up in an oil analysis report, some AMSOIL anti-wear agents are less obvious and can't be detected with common oil analysis.

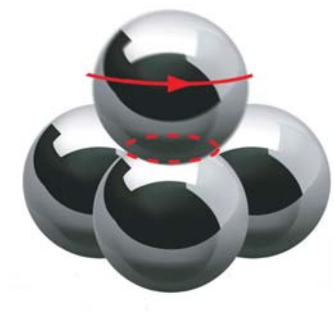

Figure 4.3
The Four-Ball Wear Test assesses the average wear scar diameter to determine a lubricant's ability to reduce wear.

Four-Ball Wear Test (ASTM D4172)

The Four-Ball Wear Test evaluates wear protection by resistance to the sliding action of a rotating ball in the fluid. The wear scar diameter in millimeters on each of the three standardized steel balls is averaged, and the number is reported as the test result (the fourth ball is discarded). The objective is for the lubricant to minimize contact and therefore produce the smallest possible scar. Testing parameters of pressure, speed, temperature and duration are variable. The diameter of the wear scars depends upon the above conditions and type of lubricant.

AMSOIL Advantage

High Viscosity Index

AMSOIL lubricants have a naturally high VI, which enables them to maintain viscosity in high-temperature conditions, providing a thicker lubricating film, while conventional mineral oils are susceptible to thinning. A thicker lubricating film, expressed as lubricant film strength, creates greater component separation and better wear protection. High VI also helps inhibit thermal runaway, a phenomenon caused by a lubricant's inability to control friction and increased heat under high-stress conditions. Controlling thermal runaway inhibits lubricant degradation and component damage, allowing equipment to run better and last longer.

Superior Anti-Wear Additive Package

Because AMSOIL lubricants have high VI properties, the need for VI improvers is reduced. As discussed in *Section 3, Understanding Shear Stability*, while VI improvers can be valuable, they are also more susceptible to shearing over time, reducing oil viscosity. AMSOIL products contain lower amounts of, and in many cases, no VI improvers, so they are more shear stable than competitors' oils.

AMSOIL uses effective anti-wear packages that protect against wear in high-speed and high-pressure applications, such as high-pressure vane and gear pumps, while still meeting the lubrication requirements of other critical components.

Soot Control

AMSOIL lubricants effectively handle soot and other contaminants. The saturated composition of AMSOIL synthetic lubricants help keep soot in suspension, which significantly minimizes large clusters that deposit on components and increase wear rates. The dispersant package in AMSOIL motor oils coupled with their overall composition provides enhanced soot control over conventional lubricants.

Resisting Rust and Corrosion

The internal combustion process in an engine generates a variety of byproducts during operation. Some of these byproducts enter the lubrication system by escaping past the piston rings (known as *blow-by*). Acidic material is one such byproduct that can lead to component corrosion when allowed to enter the lubrication system. Other combustion byproducts can mix with contaminants already present in the oil, such as water, to form additional acids that can increase the severity of the problem. To counteract acid formation, base (alkaline) additives are formulated in the oil. These additives neutralize acidic material, minimizing the potential for component corrosion and significantly extending the useful life of the lubricant.

Corrosion and Rust

Oxidation of metal may be referred to as either corrosion or rust. Rust describes the oxidation of iron, while corrosion describes the deterioration of other metals such as aluminum, magnesium, copper and/or copper-containing metals (yellow metals).

Rust protection is important in all applications, but especially in equipment that might see seasonal or sporadic use and is stored during the off-season. During storage, condensation can promote rust formation. In addition, intermittent use common with some engines creates condensation and acids that further advance the development of corrosion and rust.

Most two- and four-stroke motor oils are formulated to have an affinity to engine component surfaces, acting as a barrier that keeps condensate from contacting the components and forming corrosion. However, their effectiveness diminishes with time.

Rust is as abrasive as dirt, causing problems such as scratching and pitting on cylinders, pistons and bearing surfaces. This can lead to blow-by, low compression and reduced power and performance. When rust forms on needle bearings, failure occurs. Rust also causes excessive wear on bearings, camshafts, lifters and gear surfaces.

Most lubricants have little or no natural ability to prevent rust. They must be formulated with special rust inhibitors. However, because these inhibitors typically sacrifice wear protection by competing with anti-wear additives for the metal surface, many oils sacrifice this balance.

Humidity Cabinet Test (ASTM D1748)

The Humidity Cabinet Test (ASTM D1748) measures a lubricant's ability to protect against rust and corrosion. A standard piece of metal is immersed in the test oil before being placed in a humidity cabinet for 24 hours at 120˚F (49˚C). Following the test period, the metal is removed and inspected for rust. To pass the test, no more than three rust spots less than or equal to 1 mm in diameter are allowed. Metal panels containing more than three rust spots, or one rust spot larger than 1 mm in diameter, fail the test.

Figure 4.5
Examples of Copper Corrosion test results (left).
ASTM Copper Corrosion Standards (above).

Copper Corrosion Test (ASTM D130)

This test is designed to assess the corrosive characteristics of lubricants. In the test, a polished copper strip is immersed in a test tube with the test fluid. The entire test tube is then immersed into a bath that is heated to 212°F (100°C) or 250°F (121°C) for three hours, where the hotter temperature simulates a more severe condition. The strip is then removed, washed and evaluated according to ASTM Copper Strip Corrosion Standards. Results are reported in a range from 1a to 4c.

AMSOIL Advantage

Advanced Rust Inhibitors

AMSOIL has developed advanced formulations to specifically inhibit rust while maintaining wear-protection abilities. EP additives in gear lubricants will usually increase corrosion development, but AMSOIL has developed a precise formulation to provide high-temperature corrosion protection for yellow metals at elevated temperatures.

Decreasing Foam

Foam in an oil system can lead to poor component protection and mechanical damage. Oil viscosity, contaminants, changes in surface tension and additives can all act as catalysts to the formation of foam. Anti-foam agents can stop foaming but require effective formulation to avoid ***entrainment*** – the entrapment of tiny bubbles within a fluid.

When a fluid is agitated, trapped air forms bubbles on the fluid surface. This is commonly referred to as foam. Under compression, the foam heats up to extreme temperatures and generates steam within the fluid. Foam creates an insulating layer and prevents heat from being released; the heat and water greatly limit the lubricant's effectiveness.

Although difficult to prevent, measures can be taken to minimize this process. One way is through the use of anti-foaming agents. For example, silicone compounds, the most widely used defoamants, can be used to reduce the surface tension of air bubbles. When the surface tension is reduced, the bubbles break easily and rapidly. Silicone compounds in formulations of only a few parts per million can be extremely effective in preventing foam; however, excess amounts of these agents can promote foaming.

Organic compounds can also decrease the number of small, entrained bubbles, but require much higher concentrations than silicone. Detergents and dispersants promote foaming and minimize the effectiveness of anti-foaming additives.

Foam also promotes wear. Because air is trapped within the fluid, the fluid barrier is no longer impenetrable and metal-to-metal contact can occur. The trapped air also promotes oxidation and shortens the service life of the fluid.

Hydraulic and other industrial applications commonly require special formulations to control foaming, as they rely on the incompressibility of oil for proper performance. When hydraulic fluids foam, they become compressible and can make machinery inoperable or extremely inefficient.

Foaming Characteristics Test (ASTM D892)

Oil experiences severe air and oil churning in rotary screw compressors, increasing the likelihood of foaming and shortening oil and component service life. The Foaming Characteristics Test (ASTM D892) measures the amount of initial foaming (in millimeters) contained within an agitated fluid and compares that value to the amount remaining after 10 minutes of settling time. Generally speaking, the less foam remaining after a short time period, the better.

AMSOIL Advantage

Inherent Foam Resistance

The advanced formulations of AMSOIL synthetic oils resist oxidation and acid formation that contribute to foam development. They are fortified with anti-foam additives to suppress foam development.

Managing Water

To effectively manage water, a lubricant must address how oil and water mix, or ***emulsify***, and how they separate, or ***demulsify***.

An ***emulsion*** is a mixture of oil and water. Engine oils, due to their dispersant and detergent content, tend to emulsify with water. Emulsification keeps the water in suspension until it comes in contact with either a hot engine component or until the oil reaches normal operating temperatures (typically 200°F – 220°F). At this temperature, the water turns into steam and vents out along with other gases via the positive crankcase ventilation (PCV) valve.

Demulsibility of lubricating oil is an indication of the oil's ability to separate from water. Gear lubricants and hydraulic oils are specifically formulated with additive packages to demulsify rapidly, causing oil and water to separate.

Demulsification is very important in products where water inevitably contacts oil and must be regularly removed. In a lower unit of a boat motor, for example, a lubricant must easily demulsify to keep water away from drive gears. Compressor oils are also exposed to significant amounts of condensation. If the water is not removed, it will lead to rusting of metal surfaces and will accelerate the oxidation rate of the oil. In addition, industrial machine oils, gear oils and insulating oils require good demulsibility.

Demulsibility Characteristics Bath (ASTM D2711)

This test is used to determine an oil's ability to separate from water under conditions of contamination and agitation. The oil sample is stirred at a constant temperature for five minutes, and after a settling period, the degree of water and oil separation is measured by volume and amount of water in the oil.

Oil Demulsibility Test (ASTM D1402)

Demulsibility of compressor oil is normally determined using the Turbine Oil Demulsibility Test (ASTM D1402). In this test, 40 ml of water is added to 40 ml of the subject oil, heated to 130°F, then mixed for five minutes at 1,500 rpm and allowed to settle.

The test measures the time required for the lubricant and water to separate and also measures the cuff. The cuff is the area (measured in milliliters) between the oil and water mixture that does not separate.

Checks are recorded at five-minute intervals for up to one hour; however, final results are gathered at 30 minutes. Results are reported as "ml of oil/ml of water/cuff." Results also include a number in parentheses denoting the time required for the oil to separate completely (no cuff).

Figure 4.6
AMSOIL Synthetic Compressor Oil (shown far right), separates from water rapidly to inhibit rust formation and preserve wear protection.

For example, 35/35/10 describes oil that did not separate in the allotted time (30 minutes) and that had a 10 ml cuff. Because complete separation did not occur, no time in parentheses is given. The designation 40/40/0 (10) describes an oil that separated completely in 10 minutes. These tests show AMSOIL synthetic lubricants deliver excellent performance and meet or exceed industry standards.

AMSOIL Advantage

Focused Water Management
AMSOIL lubricants contain special additives to keep water in suspension for applications, such as motor oil, that require emulsions to properly protect equipment. These additives help prevent water and oil from separating to help prevent corrosion and sludge.

For applications that require demulsibility, such as compressor oils, AMSOIL expertly formulates oils for rapid water and oil separation.

Keeping Lubrication Systems Clean

Contaminants will inevitably corrupt any lubricating system, but quality lubricants considerably reduce contamination and extend oil service. Contamination of lubrication systems occurs in four ways.

First, the system itself can generate contamination through poor system or component design, temperature-related chemical reactions or just normal use. Second, contamination can be caused by careless packaging or handling of components before or during installation. Third, contamination can be introduced though improper or careless maintenance. Finally, contamination can be caused by another system leaking into the first system.

Base oils possess a varying degree of solvency (the ability to dissolve a solid, liquid or gas), which assists in maintaining internal cleanliness. However, commonly paired detergents and dispersants play a key role. These pairings maintain internal cleanliness by suspending contaminants, minimizing contaminant clumping (agglomeration) and preventing contaminants from adhering to components. Over time, degradation of the oil can result in a cleanliness issue, but oxidation inhibitors can reduce this effect.

Detergents added to lubricants minimize deposit formation in the high-temperature areas of an engine. The most commonly used detergents in motor oil formulations are metallic (ash) soaps with reserve basicity to neutralize the acids formed as byproducts of combustion. Other detergents include metallorganic compounds of sodium, calcium and magnesium phenolates, phosphonates and sulfonates.

Dispersants are additives that help keep solid contaminants in suspension. By keeping contaminants suspended within the lubricant, sludge, varnish and other carbon deposits are prevented from forming on engine parts. Dispersants also prevent contaminants from agglomerating into larger, potentially dangerous particles.

Dirty components run poorly, pollute and don't last. They cause system failures in engines, compressors and gear box systems that dramatically increase downtime, increase operating costs and reduce equipment life. Clean lubrication systems, on the other hand, require less maintenance, produce more energy, use fuel more efficiently, increase equipment service life and run cleaner.

Total Base Number

The ***total base number*** (TBN) of a lubricant indicates its ability to neutralize contaminants such as combustion byproducts and acidic materials. It is a measure of (alkaline) additives in the oil. Higher-TBN oils are able to neutralize a greater amount of acidic materials, which results in improved protection against corrosive reactions.

TBN levels are targeted for the intended application. For example, gasoline engine oils typically display lower TBN numbers, while oils in a diesel engine must manage the high contaminant-loading from soot and sulfur and typically run higher.

TBN levels decrease as the oil remains in service. When the level reaches a point where it can no longer protect against corrosion, the oil must be changed.

Oils that are formulated specifically for extended drain intervals typically display elevated TBN numbers to ensure proper corrosion protection for the duration of the extended interval.

Base Number Test (ASTM D2896/ASTM D4739)

The Base Number Test measures the detergents and dispersants in new oils.

Two tests are commonly used in the industry to calculate TBN. ASTM D2896 typically results in slightly higher TBN values than ASTM D4739.

AMSOIL Advantage

High TBN

Because AMSOIL lubricants contain consistently high TBNs, they neutralize acidic contaminants formed during the combustion process and keep these contaminants in suspension to prevent corrosion.

AMSOIL lubricants use detergent and dispersant additives to significantly reduce sludge and carbon deposit formation better than conventional oils.

Elastomer Compatibility

Elastomer/seal compatibility of a lubricating fluid is extremely important in ensuring proper equipment operation. Common problems that can result from seal/oil incompatibly include the degradation, shrinking or swelling of the seals.

AMSOIL Advantage

Seal Compatibility

Seal compatibility and seal conditioning is an important characteristic of a lubricant's formulation. AMSOIL lubricants condition seals, maintaining their ability to function correctly by inhibiting contaminant penetration at the seal. Because seal materials are sensitive to thermal conditions, the inherent thermal control of AMSOIL synthetic lubricants promotes seal life and integrity.

Total Package Performance

AMSOIL has an advantage over competitors because AMSOIL synthetic lubricants do not rely on additives alone to protect equipment. While other oil companies use only one base oil type as the main component, AMSOIL uses many different base oils and additives, taking advantage of their unique properties. Doing so builds better anti-wear and EP performance. The unique combination of multiple base oils delivers better performance than oils constructed with a single base oil. When combined with a tested and balanced treatment of the best additive packages, AMSOIL synthetic lubricants excel in protecting equipment.

Customers should never use a lubricant based solely on its performance in a single area. Lubricants must perform well in all areas in order to be suitable candidates. Choose a lubricant based on its total performance characteristics. Only when an oil's base stocks and additive package are working in unison will it be capable of providing the required basic functions of a lubricant, including the following:

1. Reducing friction and wear
2. Cleaning
3. Cooling moving elements
4. Preventing contamination (seal)
5. Dampening shock
6. Transferring energy
7. Preventing corrosion

Lubrication Fundamentals
Section 5: The Storage and Handling of Lubricants

Section 5 discusses the shelf life of AMSOIL synthetic lubricants and their proper storage and handling. These procedures and recommendations help maximize product life, and proper storage is essential to ensure that environmental contamination does not occur.

Section Objectives

After studying Section 5, you should understand and be able to explain the following terms and concepts:

1. The three C's of lubricant storage
2. The six factors contributing to lubricant shelf life
3. The ideal temperature for lubricant storage and why
4. The negative consequences of contamination
5. How water can be introduced into the lubricant and ways to prevent it
6. How agitation can degrade the lubricant
7. AMSOIL lubricant overall shelf life
8. Ideal inventory supply
9. Improper lubricant storage and handling
10. The physical characteristics of an unusable lubricant
11. Proper lubricant storage techniques
12. Storage techniques for different container types

Section Keywords

The following keywords are defined in this section.

Bleeding
Breathers
Thermal siphoning

Proper Storage and Handling of Lubricants: The Three "C's"

Proper storage and handling of lubricants can be achieved by remembering the three "C's": ***C**ontamination control*, ***C**larify* and ***C**ontainment*. These are the most important factors when storing lubricants, both long- and short-term. Proper storage will extend the lubricant's shelf life and maintain its integrity.

Lubricant handlers and shop technicians don't typically receive proper training on the best practices for lubricant storage, which can jeopardize lubricant quality and performance.

The shelf life of lubricants is not indefinite, even if stored in optimal conditions. All lubricants have a shelf life that is heavily influenced by lubricant chemistry and environmental conditions.

Lubricant Shelf Life

The storage environment of a lubricant greatly affects its shelf life and can vary for a number of reasons. Some of the primary factors are discussed below.

Chemistry of the Product

A lubricant's chemistry affects its shelf life. Some lubricants will naturally last longer than others due to additive packages that can influence storage time limits.

Temperature

Ambient temperature is important to maintaining the quality of the lubricant during storage. Extreme hot or cold temperatures negatively affect oil life. Fluid separation, referred to as bleeding, mostly occurs in greases and is made worse by high temperatures.

For best results, lubricants should be stored in a steady, temperate environment between 45°F and 80°F (7°C and 27°C).

Water

Water reacts with lubricant additives and can result in the formation of insoluble materials, microbial growth and oil degradation.

Water can be introduced into storage containers through improper handling or damage. Container breathing can introduce contamination, such as water and environmental particulates, into the lubricant as air moves between the outside of the container and the cavity where there is no lubricant present. This phenomenon is termed thermal siphoning. Contamination from ***thermal siphoning*** can be controlled with proper equipment and storage practices.

Breathing of storage containers cannot be avoided, but there are measures that can be taken to reduce contamination from this mechanism. Solutions to this problem are discussed in the Lubricant Storage section.

Contamination

Contaminants introduced into oil will shorten product shelf life. For example, iron, copper and other elements act as oxidation catalysts. The type of storage container can also affect the amount of contamination to a lubricant. Metal barrels, which are susceptible to rust formation from atmospheric moisture, are not ideal for storing liquids since rust particles can shed from the container and contaminate the lubricant.

Agitation

Frequent agitation of a lubricant can result in air being trapped in the oil, which negatively affects lubricant viscosity and consistency. Agitation will also emulsify water that may be present, further degrading the oil and producing harmful chemical byproducts.

Light

In some cases, light may affect the color and appearance of lubricants; UV rays can accelerate breakdown of chemical bonds, resulting in reduced performance.

Lubricant Storage

Drum Storage

Storing oil in drums is troublesome and potentially hazardous. Drums should be stored on their sides with the bungs below the liquid level to prevent water condensation from collecting in the drum rims. To prevent against drum leakage, bung seals should be moistened with the lubricant in the container. For drums with taps, drip trays should be used to collect leakage.

Oil drums should never be stored directly on the ground, while the height of stacked drums should never exceed two barrels. If more storage capacity is needed, consider a special-purpose racking system, which is discussed on the next page.

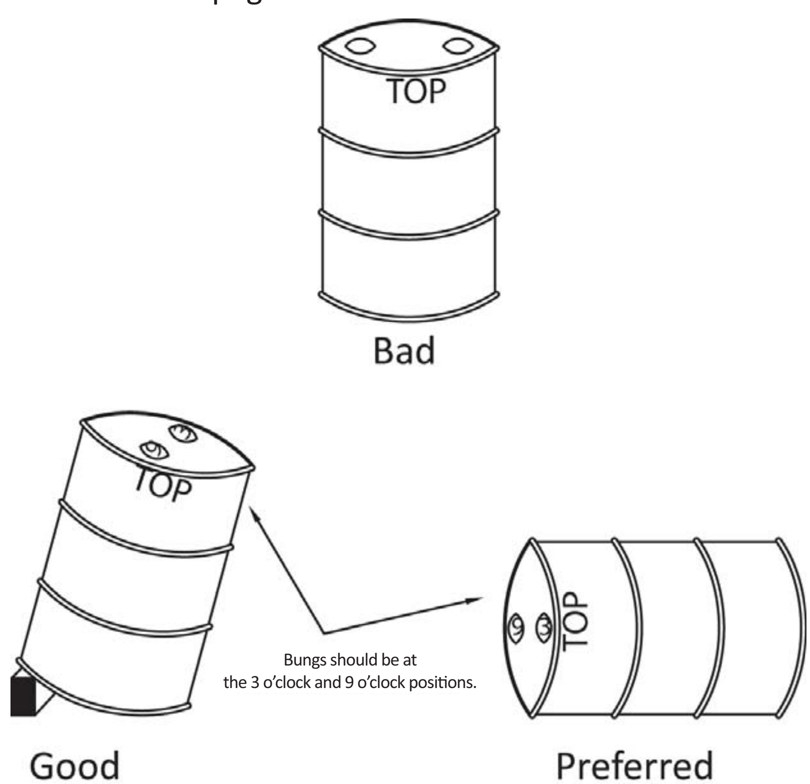

Figure 5.1
Proper oil drum storage positioning.

Plastic Storage Containers

Polypropylene storage containers are ideal for lubricants. They pose no risk of contamination from rust and are clear so the lubricant level can be easily determined. These containers also come in a range of sizes and shapes for easy handling and storage.

These containers can be fitted with hoses and filtered breathers to facilitate easy dispensing and contamination control.

Small Packages

Small amounts of lubricants that come boxed in cardboard should be stored indoors, under cover to avoid environmental contamination and degradation.

First In/First Out Rotation Planning

First in/first out rotation planning should be practiced so that the oil is adequately rotated for maximize shelf life.

Storage Racks

Storage racks can be easily built or purchased from third-party vendors for safe and easy access. Many storage systems incorporate spill-collection reservoirs to catch spills or leaks, which helps prevent environmental contamination and avoid hazardous cleanup.

Signs of Improper Storage or Lubricant Contamination

If a stored lubricant exhibits any of the following characteristics, either it has been contaminated or it has exceeded its shelf life. In such instances, AMSOIL advises properly disposing of the lubricant to avoid pollution.

1. Layering within the fluid
2. Formation of solid particles
3. Color change or hazy appearance

If the quality of the oil is questionable, oil analysis may be conducted to determine if the product has retained its original specifications for serviceability.

Contamination Control

Contamination of lubricants can be avoided with proper storage and labeling. Make sure all storage containers are fitted with breather units to reduce atmospheric contamination that can occur from thermal siphoning.

Use quality storage containers, preferably plastic, to reduce the occurrence of contamination coming from the storage container itself (i.e. rust from a metal barrel).

Improve labeling systems to avoid cross-contamination of different grades and types of lubricants.

Store containers in a clean, indoor environment when possible.

If indoor storage is impossible, take proper precautions to shelter storage containers from environmental contamination, such as rain, snow and other elements. Lay drums on their sides with the bungs at a 3 or 9 o'clock position to retain seal integrity and avoid excessive breathing. Drums stored upright should be covered so that moisture does not collect around the bungs.

Clarify & Containment

Lubricant management can reduce cross contamination and mishandling. To avoid costly or disastrous mistakes, clearly mark all containers with durable labels. When lubricant storage and blending equipment is clearly marked, contamination from other oils and additives can be minimized or eliminated. Extra precautions should be taken for any containers stored outdoors to avoid weather-related damage.

To increase the effectiveness of labeling, consider using color- or shape-coded systems to simplify the identification process. If a color-coded system is used, another coding system should also be used to account for color-blind individuals.

A coded system should also be applied to all dispensing equipment, as this is one of the most common contamination sources. Pumps, hoses and other dispensing tools should be properly labeled for their corresponding lubricant. If transport carriers and filter carts must be shared between lubricants, implement a thorough cleanup and flushing procedure.

Re-suspending of Additives

Lubricants that have been stored for an excessive time should be agitated on a drum tumbler or swirled manually to mix in additives that may have fallen out of solution during storage. A rotation system should be used to ensure adequate turnaround and usage rates.

Safety & Handling

Ensure absorptive materials are available for accidental oil spills.

AMSOIL recommends that good personal hygiene practices be enforced after the handling of all lubricants, including washing skin contact areas with soap and water and cleaning oil-soaked clothing.

Health and safety information is provided for every lubricant AMSOIL distributes. Consult product Safety Data Sheets (SDS) for questions regarding specific health and safety concerns and handling guidelines. These are available from AMSOIL INC. and can be obtained on the AMSOIL corporate website (www.amsoil.com), or by calling (715) 392-7101.

AMSOIL Product Shelf Life Recommendations

Under ideal storage conditions, AMSOIL lubricant shelf life is five years, but rotation is recommended every three to 12 months.

For lubricants stored for long periods, AMSOIL recommends reviewing product specifications because specifications change and old products may be obsolete for new equipment.

Grease should be physically evaluated to ensure no excessive bleeding has occurred and that the grease has retained its proper consistency.

Proper Storage Guideline Summary

1. Store lubricants in a cool, clean and dry indoor location.
2. Ambient temperatures should be between 45°F and 80°F (7°C and 27°C).
3. Ensure environmental contaminants (dust or moisture) do not enter the storage container.
4. Clean the tops of the storage containers to avoid future contamination during handling.
5. Always use clean tools when handling lubricants.

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