Lubricants and Lubrication - from the Well to the Applications

By Neville W. Sachs, P.E., CLS
Applied Technical Services, Inc.
Marietta, GA
www.atslab.com

Our Plan

- A little bit about the lubricants industry
- Explain the basics of how lubricants work in different applications
- Discuss the important lubricant properties and additives
- Explain what problems occur with lubricant applications.

Quiz questions!!!!!

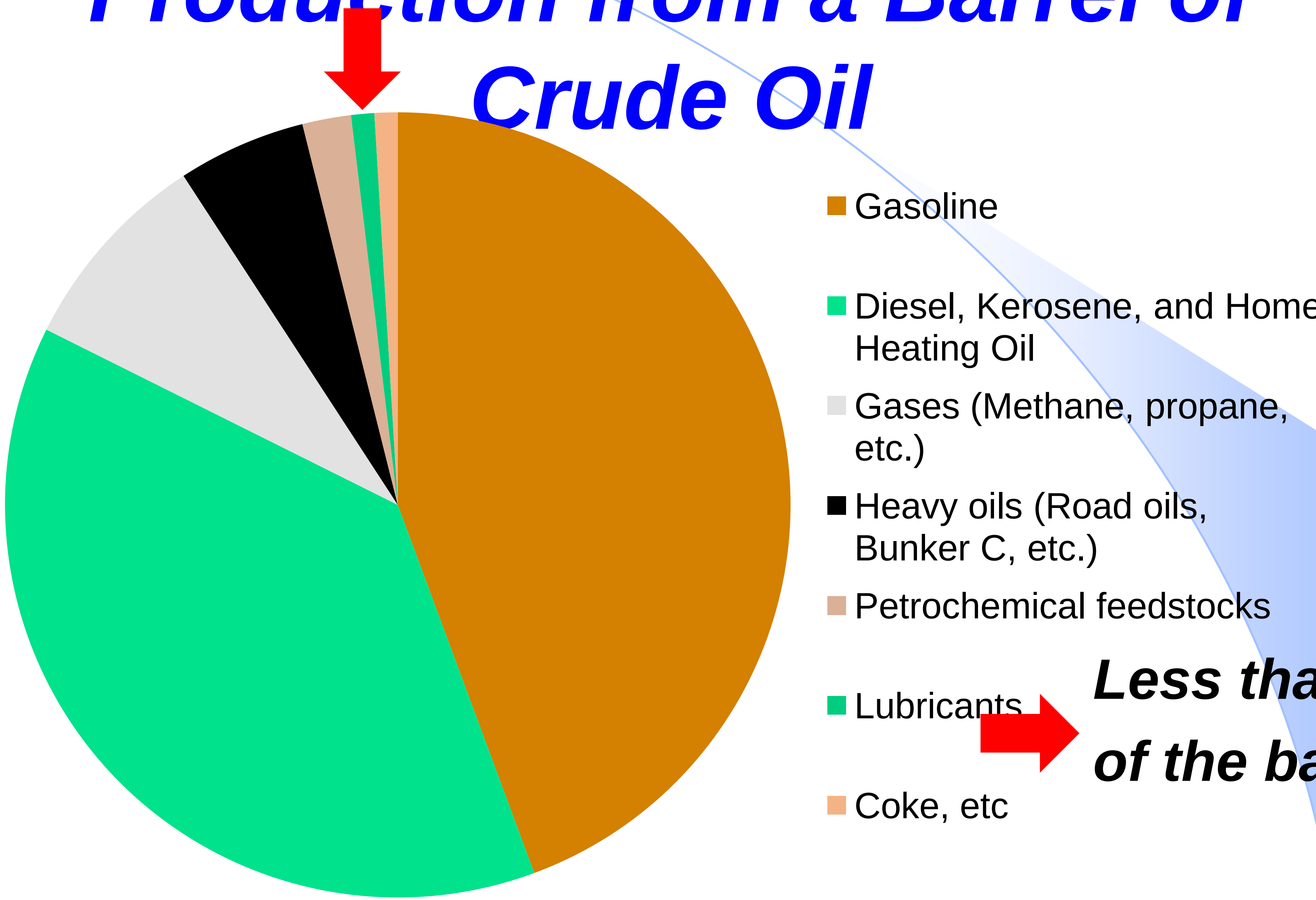
1. Define “viscosity index”.
2. About what percentage of all lubricants is used in cars and light trucks?
3. As the type of bearing rolling element changes, what is the effect on the required viscosity for high speed lubrication?
4. What are the mechanisms that allow “EP” additives to reduce component wear?
5. What effect would solid “EP” additives have on rolling element bearings running at 600 rpm?
6. What effect would solid “EP” additives have on rolling element bearings running at 6 rpm?
7. What are some differences between PCMO oils and turbine oils?

Conventional Crude Oil

Distilled at the refinery in a “fractionating tower”

- Lighter oils come off at low temperatures
- Heavier oils need higher temperatures

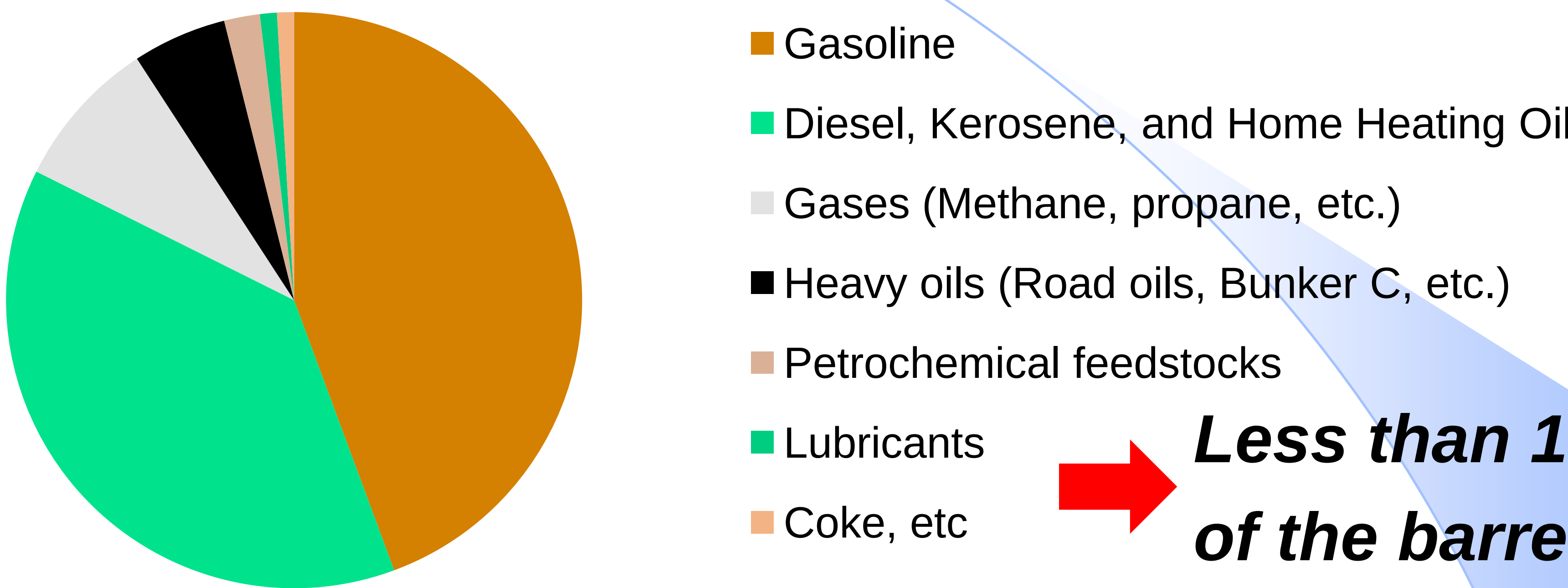
Production from a Barrel of Crude Oil



Less than 1% of the barrel

Source – US Department of Energy

Production from a Barrel of Crude Oil

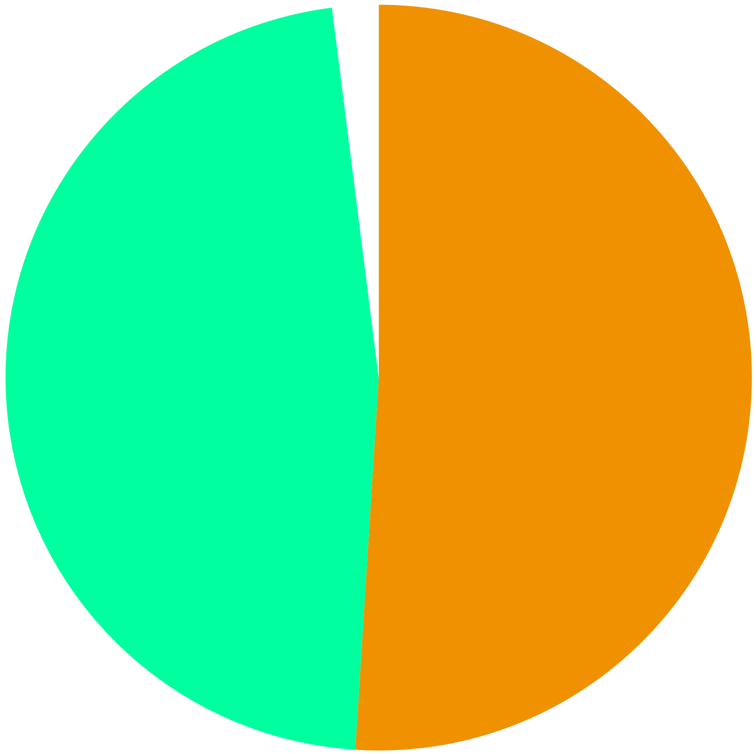


Less than 1% of the barrel

From this, we can see that the lubrication world is a very small part of the overall refining business!

Source – US Department of Energy

Where does that production go?

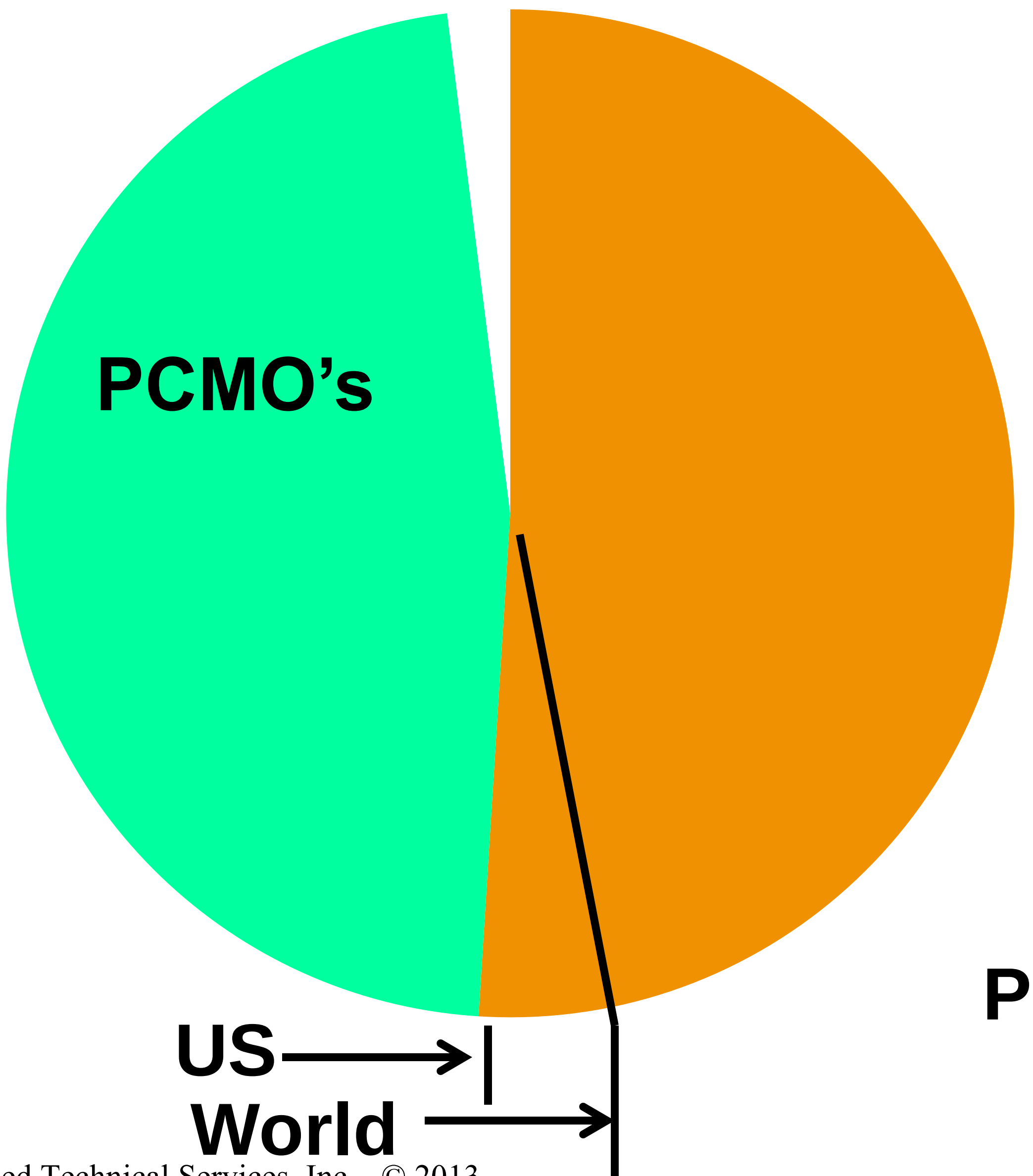


Usage	US	World-wide
Industrial	51	41
Automotive	47	56
Greases	2	3

The US Refinery Production for 2013 was about 60,000,000 barrels

60,000,000 barrels x 42 gallons/barrel = 2.5 billion gallons

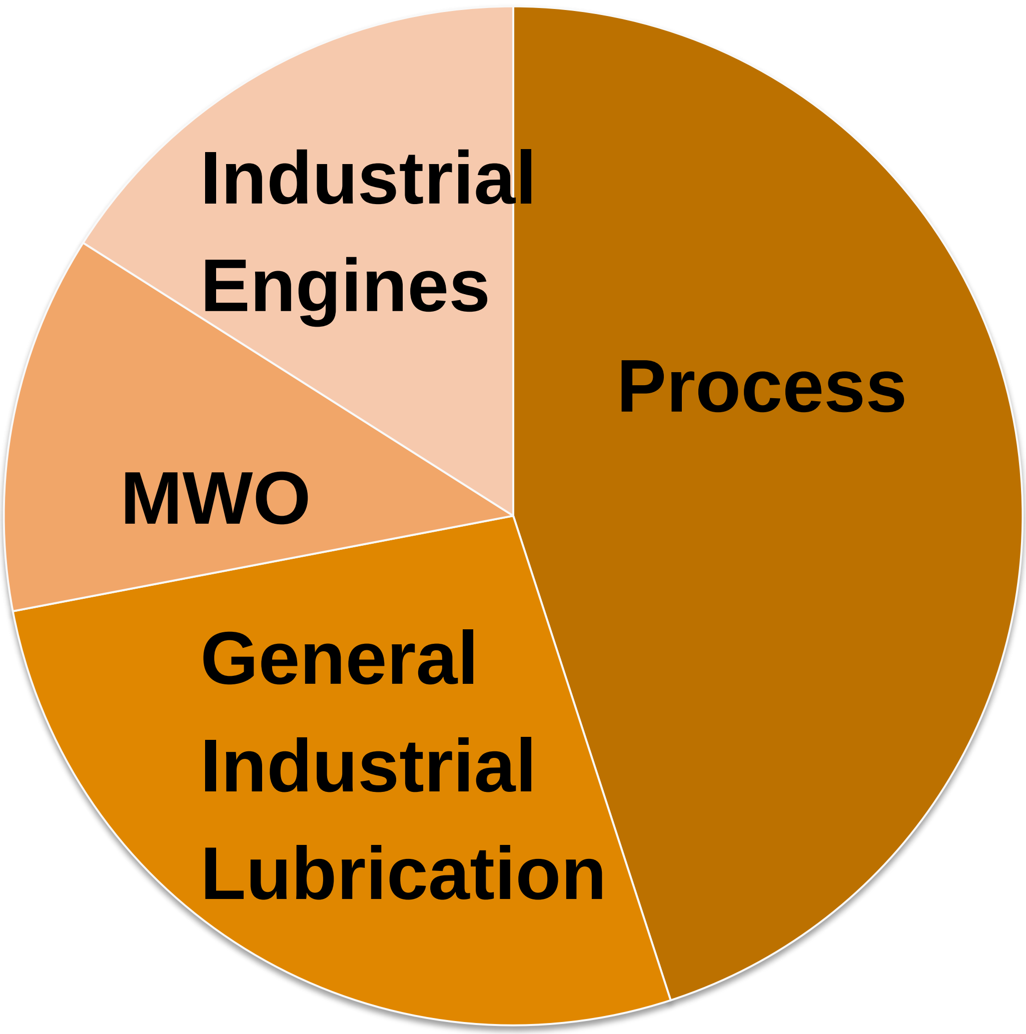
How are lubricants used?



Category	US	World - wide
Industrial	*51*	*41*
Automotive	*47*	*56*
Greases	*2*	*3*

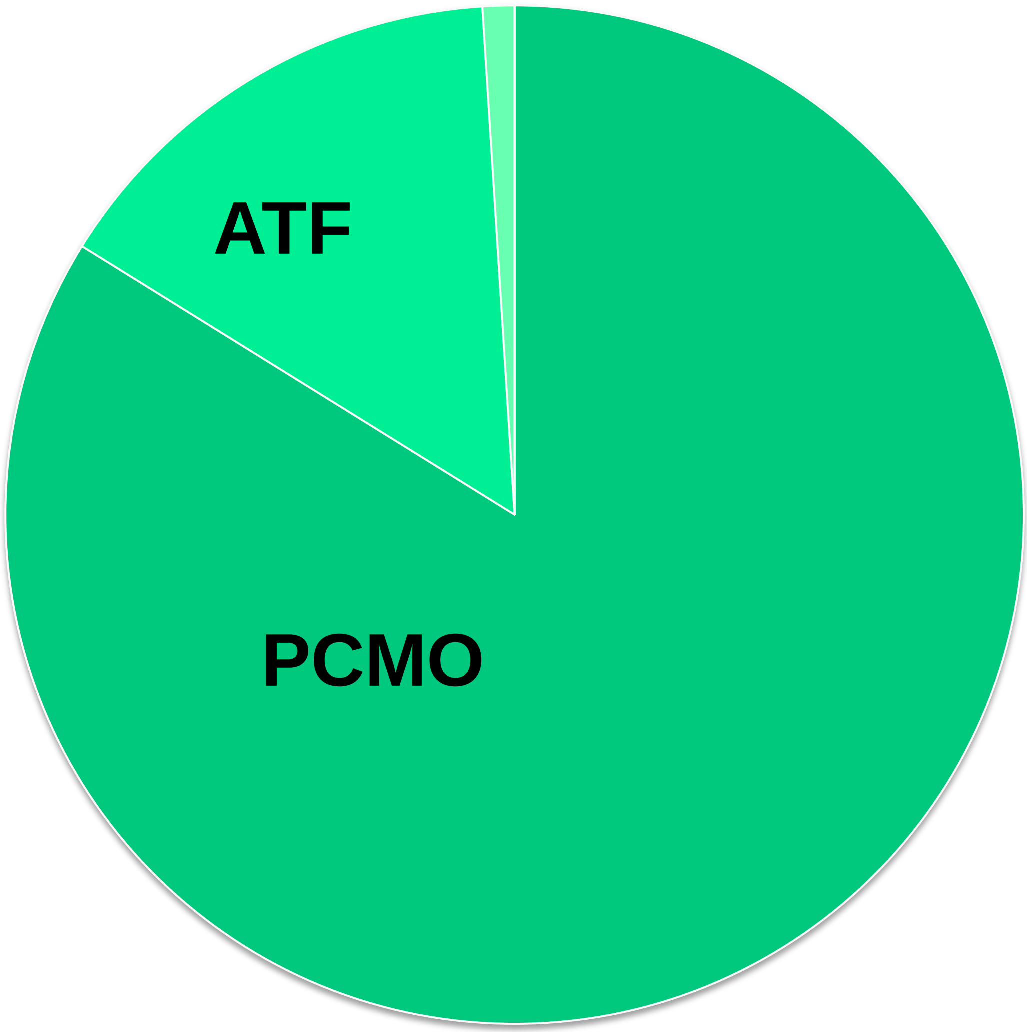
PCMO = Passenger Car Motor Oils

When we look at the industrial usages we see



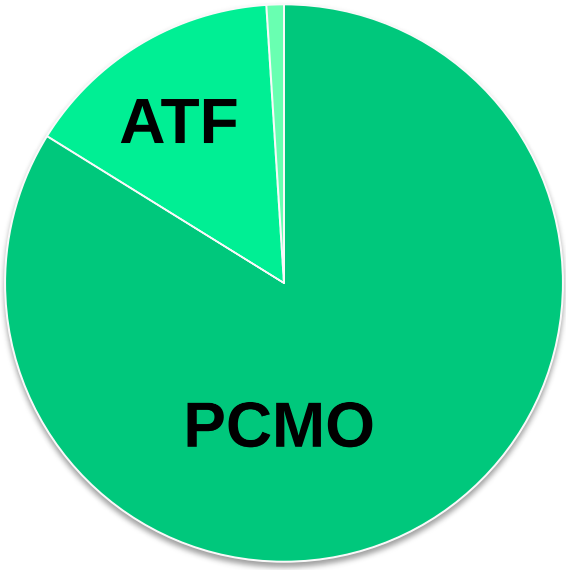
Category	%
Process Oils	45
General Industrial Lubricating Oils	27
Metalworking Oils	12
Industrial Engine Oils	16

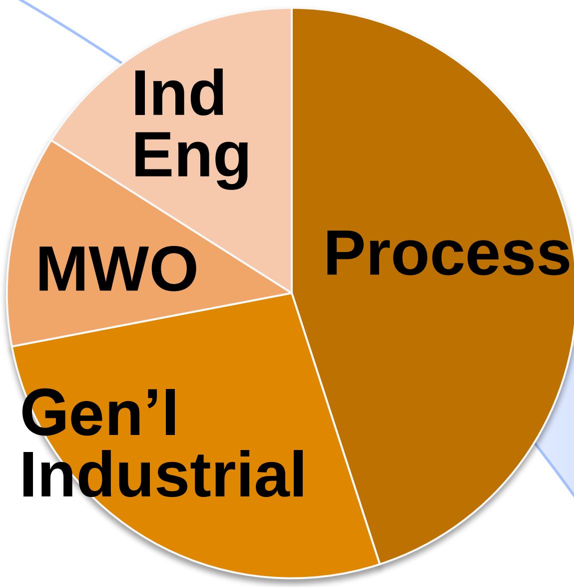
But when we look at Automotive Lubricants …



Category	%
Multigrade Engine Oils (PCMO)'s	83
ATF and Hydraulic Fluids	15
Other Automotive Oils	≈2

Automotive Lubricants





Unfortunately for those of us primarily involved with industrial applications, automotive lubricants are at about 50% of the total lubricants market, and engine oils are over 80% of that,

so guess what drives most lubricant research!

Conventional Mineral Oil

Distilled at the refinery in a “fractionating tower”

- Lighter oils come off at low temperatures
- Heavier oils need higher temperatures

Synthetic Oils

That depends

Some are made from distilled crude that undergoes additional procession

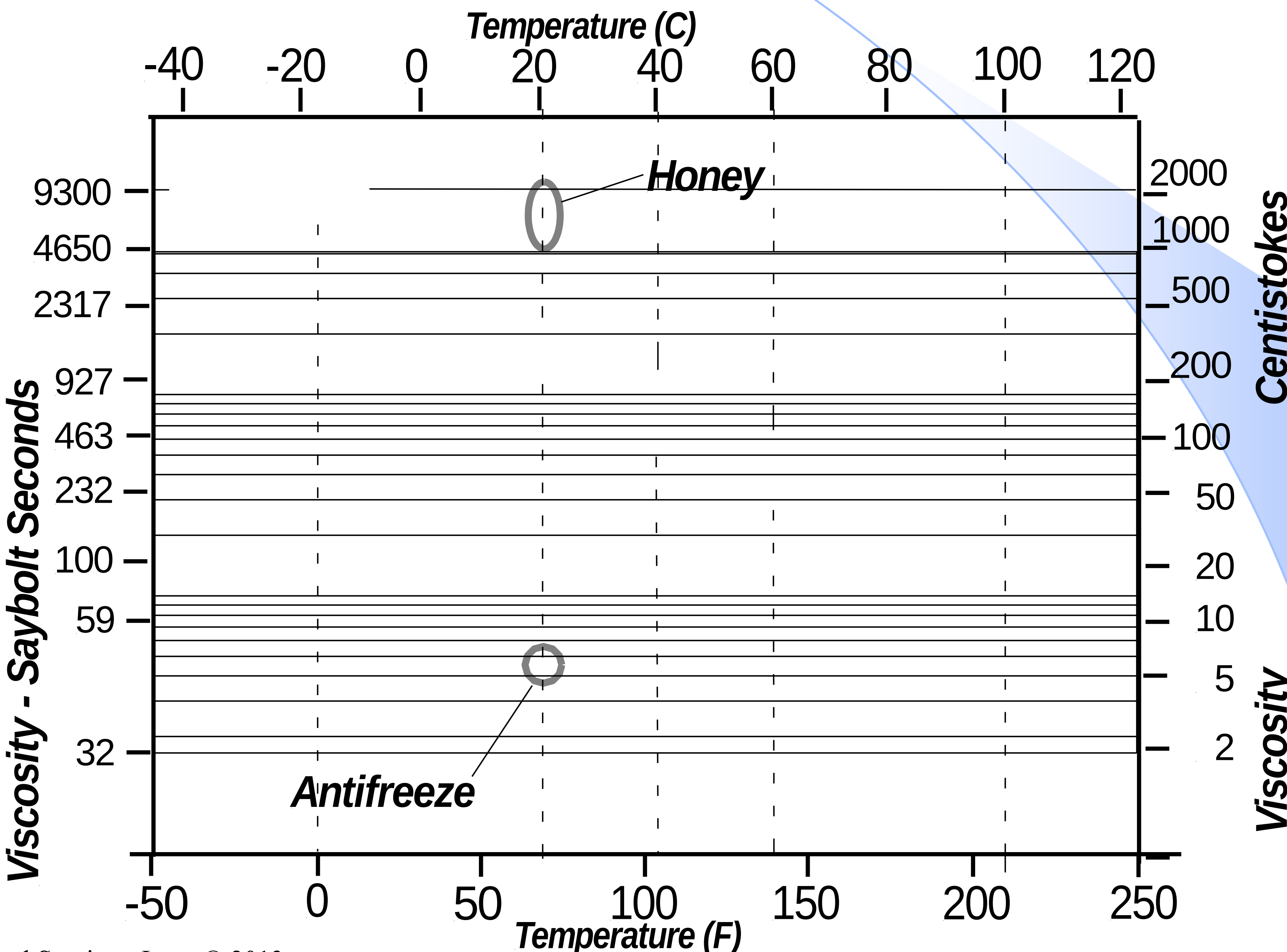
Some are truly synthesized from gases and other chemicals (PAO, PAG, etc.)

What is “viscosity” and how is it defined regarding automotive oils?

Viscosity is a measure of a liquid’s resistance to shear, i.e., a measure of how readily the liquid flows.

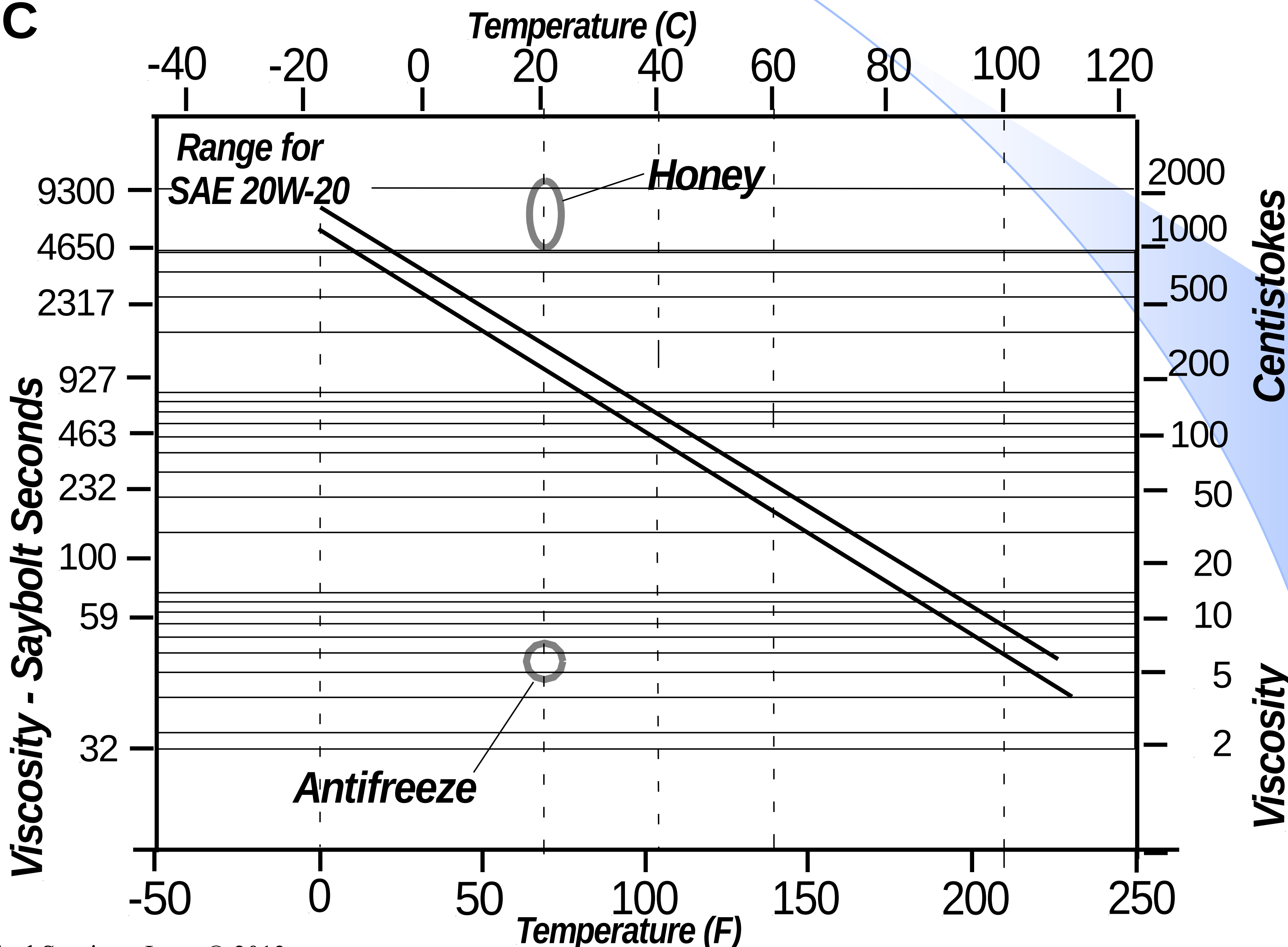
The viscosity of an industrial oil is usually specified at 40^0C (104^0F) while automotive oils are specified at both -18^0C and 100^0C

Viscosity vs. Temperature



Viscosity vs. Temperature

SAE 20W-20 engine oil with viscosity spec'd at both -18^0 and 100^{0}C



A viscosity experiment

How are the typical viscosity ranges defined regarding industrial oils?

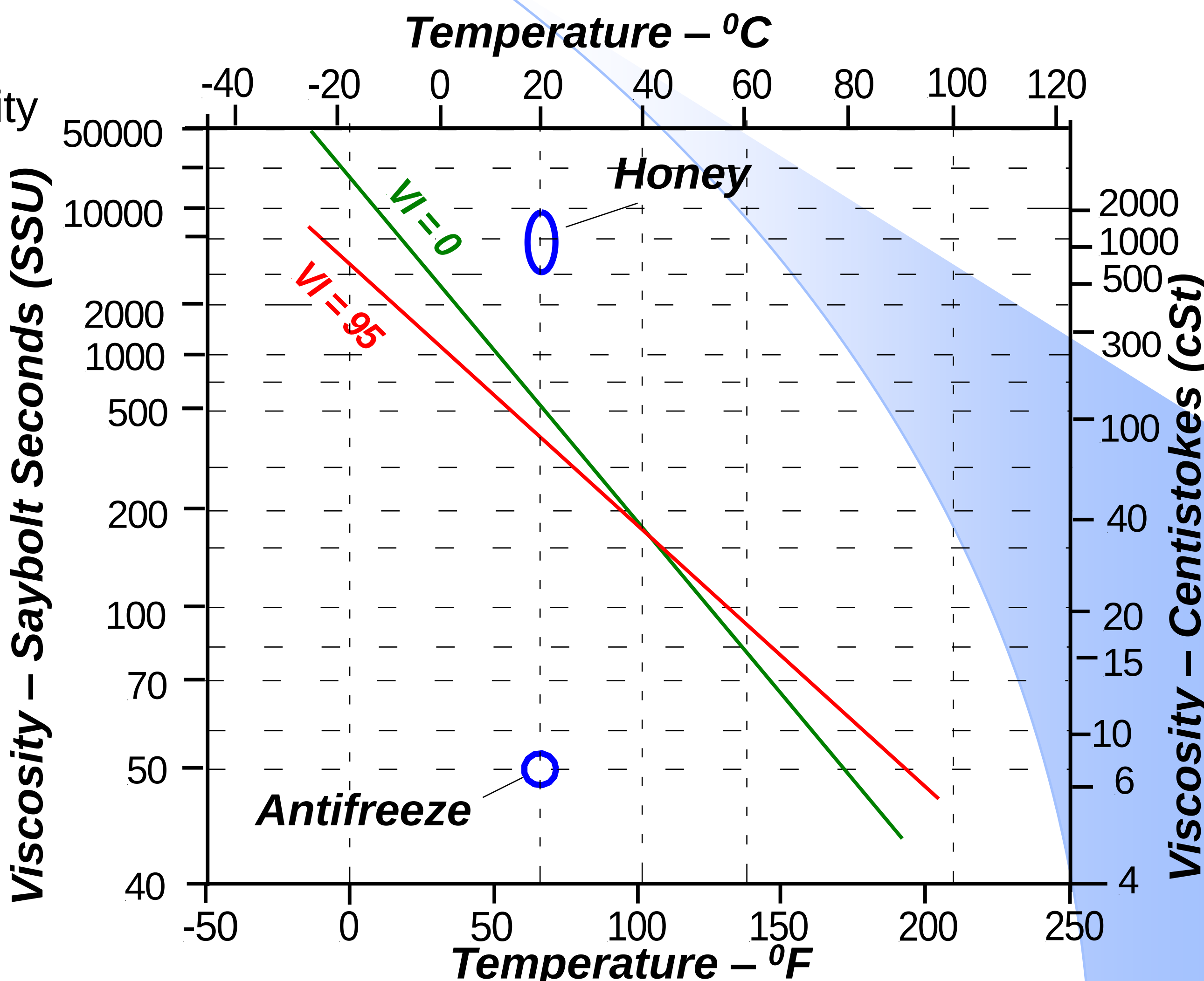
The viscosity of an industrial oil is usually specified at 40^0C (104^0F).

However different formulations may result in two oils that have identical viscosities at 40^0C, but very different viscosities at another temperature, e.g., -17^0C (0^0F)

This difference in the rate of change is because the two oils have different "***viscosity indexes***" ***(VI's).***

Understanding the Viscosity Index

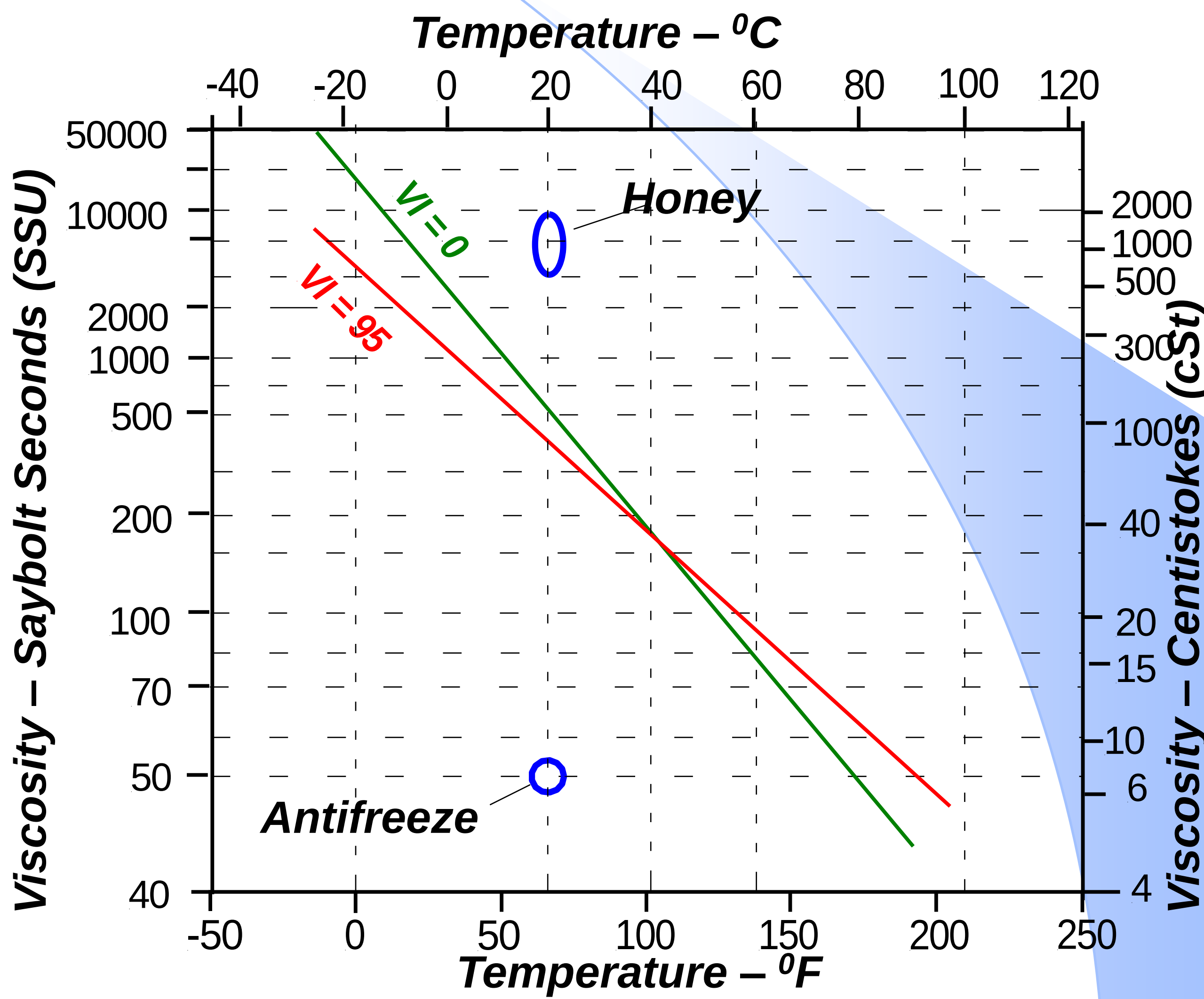
ISO Standards call for the viscosity of oils to be rated at 40^0C. But, as the temperature increases, some oils become much more fluid than others. These oils that "thin" more rapidly have a lower ***viscosity index.***



Viscosity Index

The chart below shows the ***viscosity index*** for some common crude oil sources.

Crude Source	*Typical Viscosity Index Range*
Pennsylvania	90-100
North Sea	55-70
West Texas	45 -60
North Slope (Alaska)	10-30
California	0-20



Viscosity Index – from another view.

Notice the huge difference at higher temperatures.

The chart below shows the ***viscosity index*** for some common crude oil sources.

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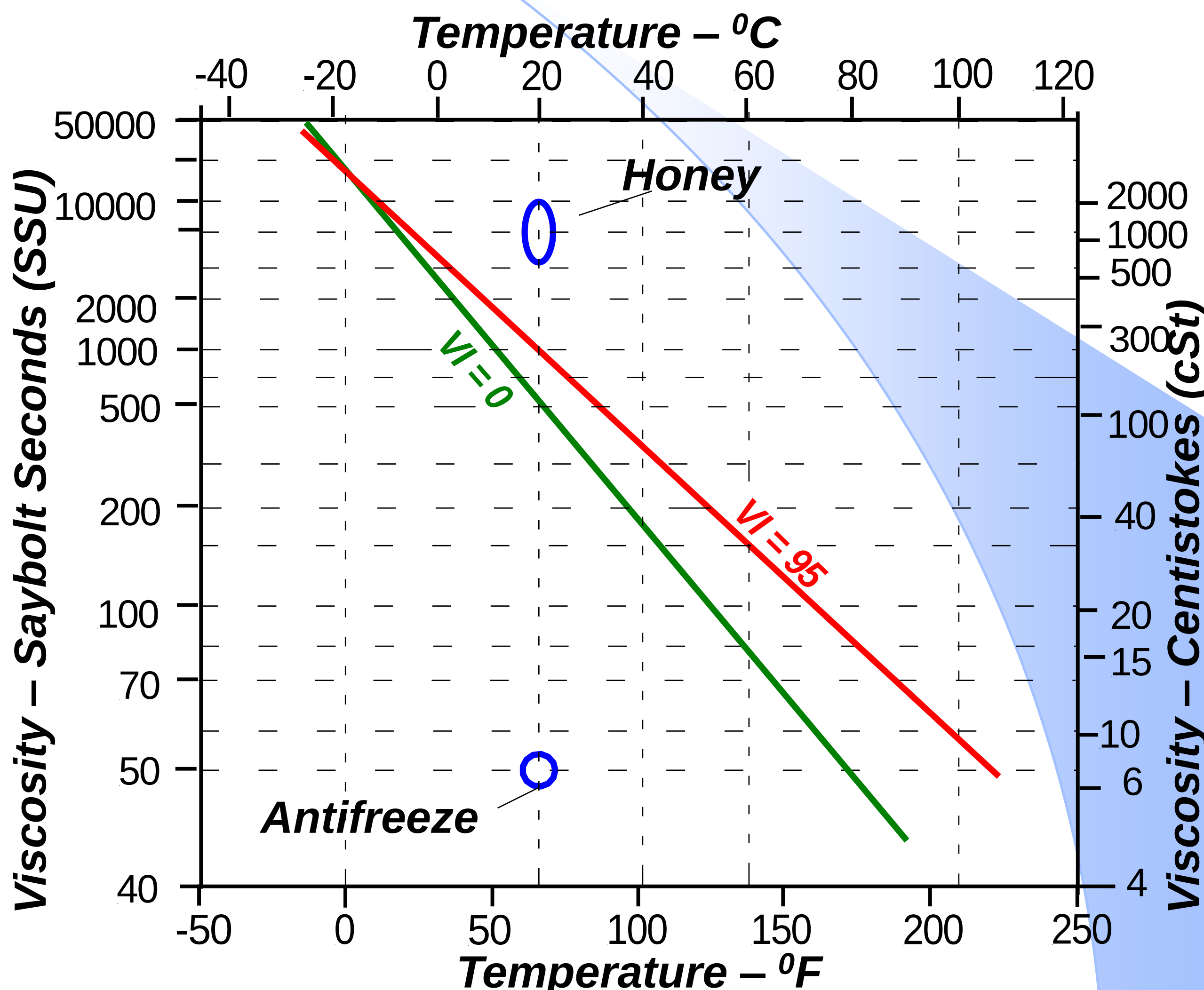


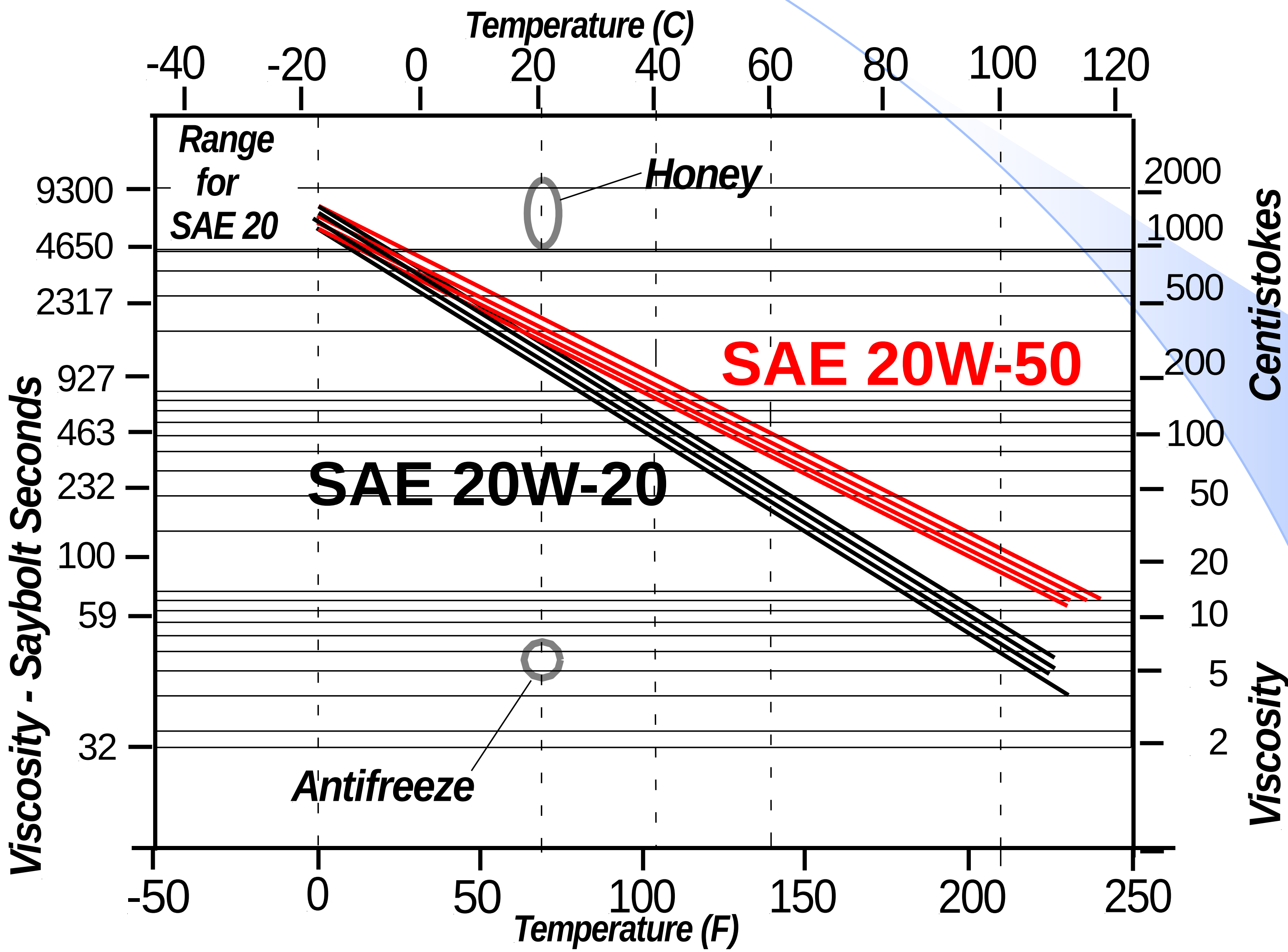
Back to Automotive Engine Oils

We'll look at engine oils, comparing a 20W-20 with a "multi-viscosity" 20W – 50

[The "W" indicates the viscosity at 0^0F (-18^0C)]

Viscosity vs. Temperature

with a typical multi-viscosity engine oil



Oil and Grease Additives

Viscosity Index Improvers
Detergents and Dispersants
Pour Point Depressants
Emulsifiers and Demulsifiers
Rust and Corrosion Inhibitors
Extreme Pressure Additives
Oxidation Inhibitors
Antifoam Agents
Antiwear Compounds
Friction Modifiers

Depending on the application, different **base oils** and the compatible additives are selected.

Where additives are used

Lubricant	Additives							
	Oxidation Inhibitor	VI Improver	Pour Point depressan	Emulsifier/ Demulsifie	Defoamer	Detergent/ Dispersant	AW or EP	Corrosion Inhibitor
Automotive engine oils	xx	xx	xx		xx	xx	xx	xx
ATF	xx	xx	xx		xx	xx	xx	xx
Industrial gear oils	xx	x	x		xx		xx	xx
Hydraulic fluids	xx	x	x		xx	xx	xx	xx
Turbine oils	xx			xx	x			xx
Metalworking fluids	xx			xx	x	x	x	xx
Greases	xx	x	x	x			xx	x

“xx” indicates an additive is essentially always used

“x” indicates an additive is sometimes used

Let's look at the different additives on the handout

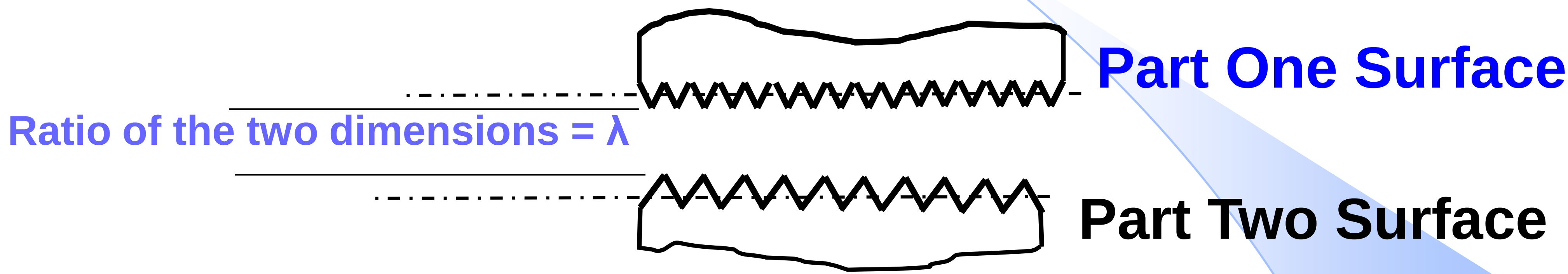
Oil and Grease Additives

Lubricants are a combination of the base oil and the additives and the specific combination depends on the properties of both.

Examples:

- Gear oils need antiwear or EP additives.
- Turbine oils need good demulsibility while wheel bearing greases need emulsibility.
- Oils that operate over a wide temperature range need VI improvers.
- Hydraulic oils need antiwear additives but rarely need EP additives.

How does a Lubricant Prevent Wear?

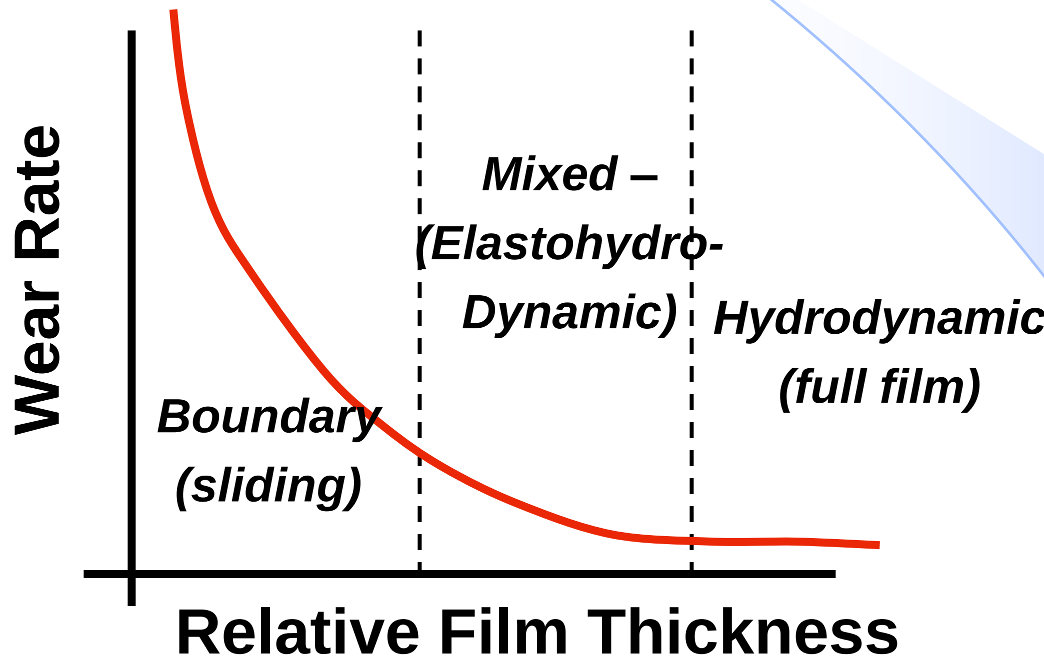


This sketch shows a greatly magnified view of two parts separated by a lubricant film. The separation is important because the greater the distance, the less the parts contact each other and less wear occurs. The Greek symbol lambda, λ, is usually used to denote the relative film thickness.

λ is a result of the viscosity, relative speed, and the shape (relative roughness) of the parts.

λ vs. Wear Rates in Normal Operation

General Lubrication Regimes

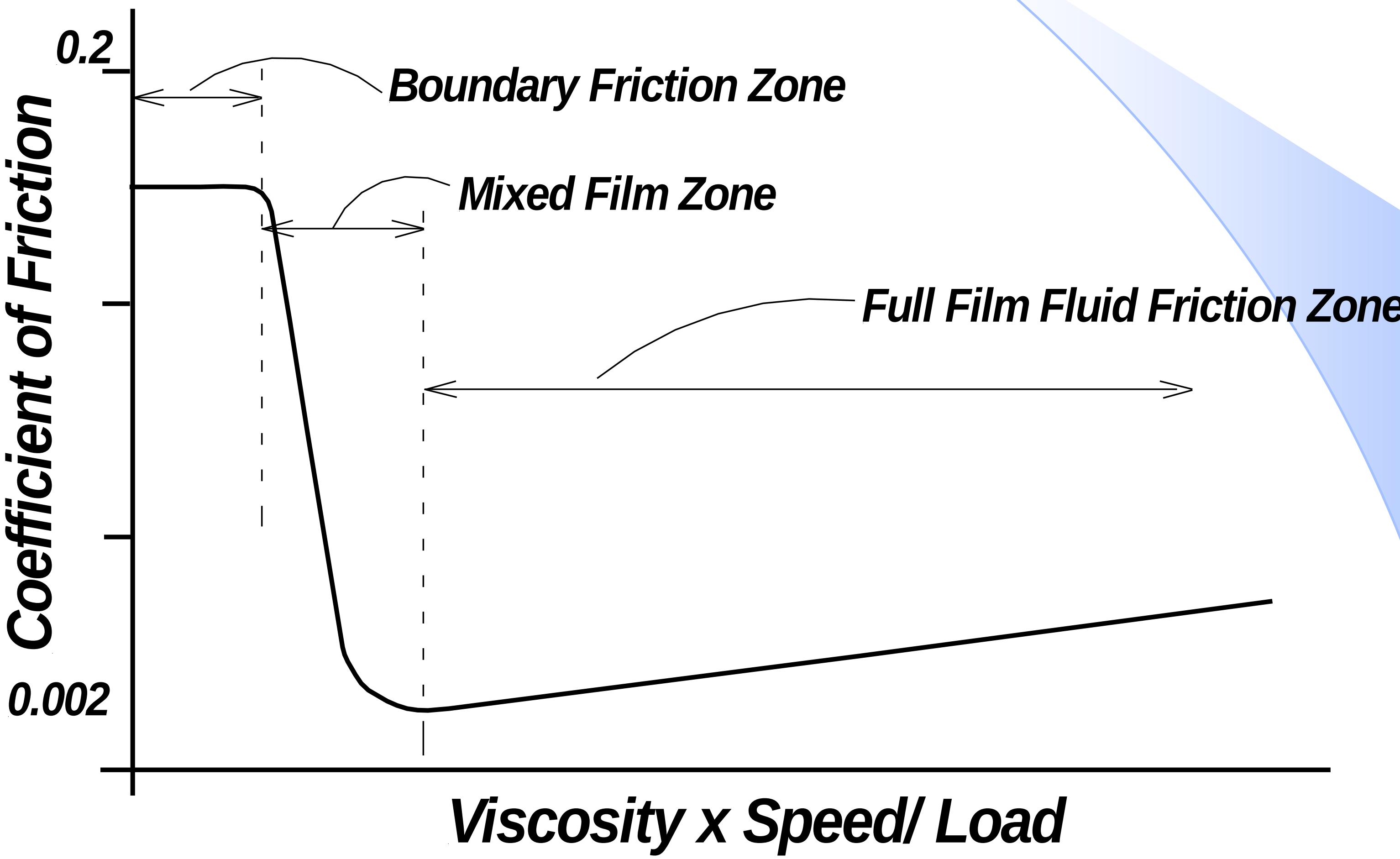


This graph shows how important the lubricant film thickness is in controlling the wear rate.

Viscosity is most important on the right side of the graph while the key to reducing friction on the left side is the additive film.

Friction changes with conditions

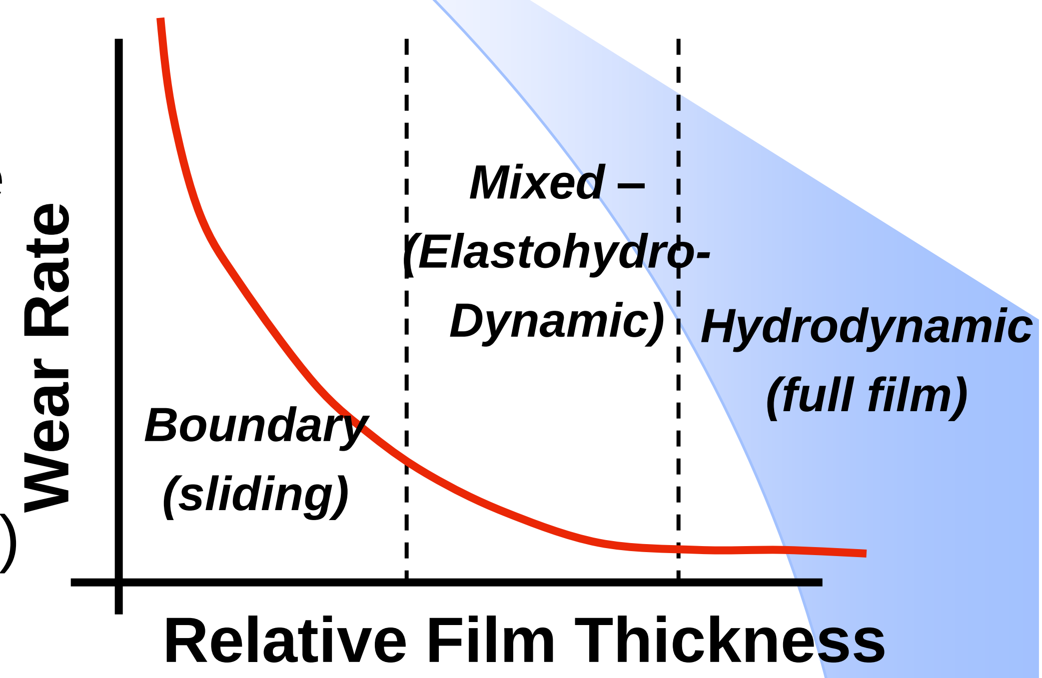
Stribeck Curve



The Three Basic Bearing Configurations

- ***Sliding Bearings –*** and low-speed plain bearings usually use boundary lubrication
- ***Plain Bearings -*** with oil they use hydrodynamic lubrication (but grease bearings can use boundary films).
- ***Rolling Element Bearings -*** using elastohydrodynamic (mixed) lubrication
- ***Combinations -*** moderate speed gears or low speed bearings

Wear Rates and Film Thickness



Rolling Element Bearings

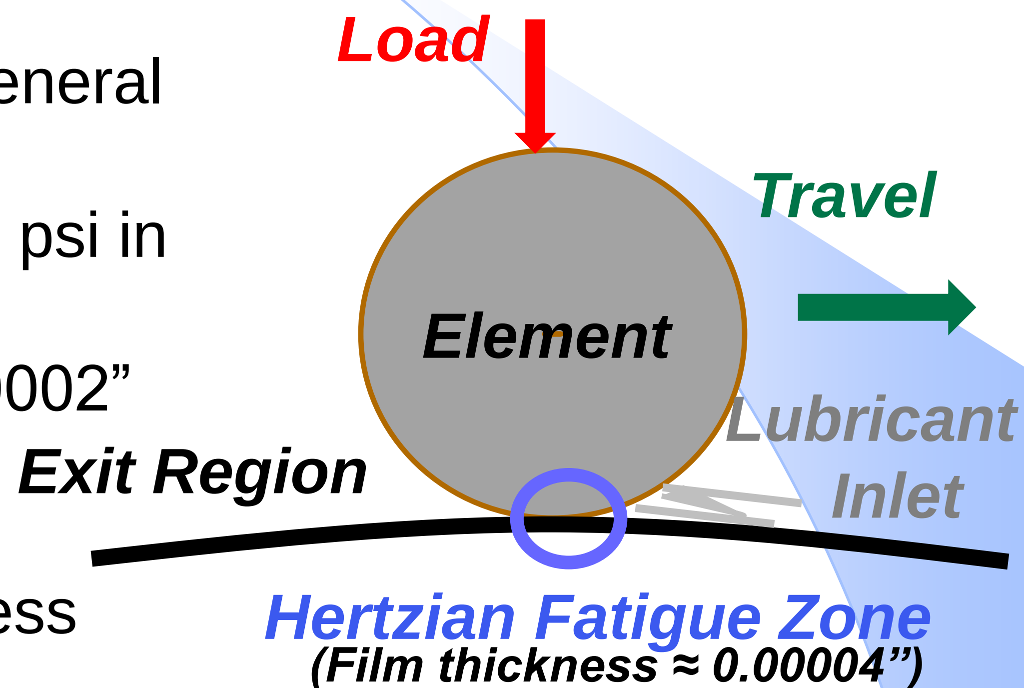
Ball and Roller Bearings - in general industrial equipment

Pressures - As high as 300,000 psi in the load zone

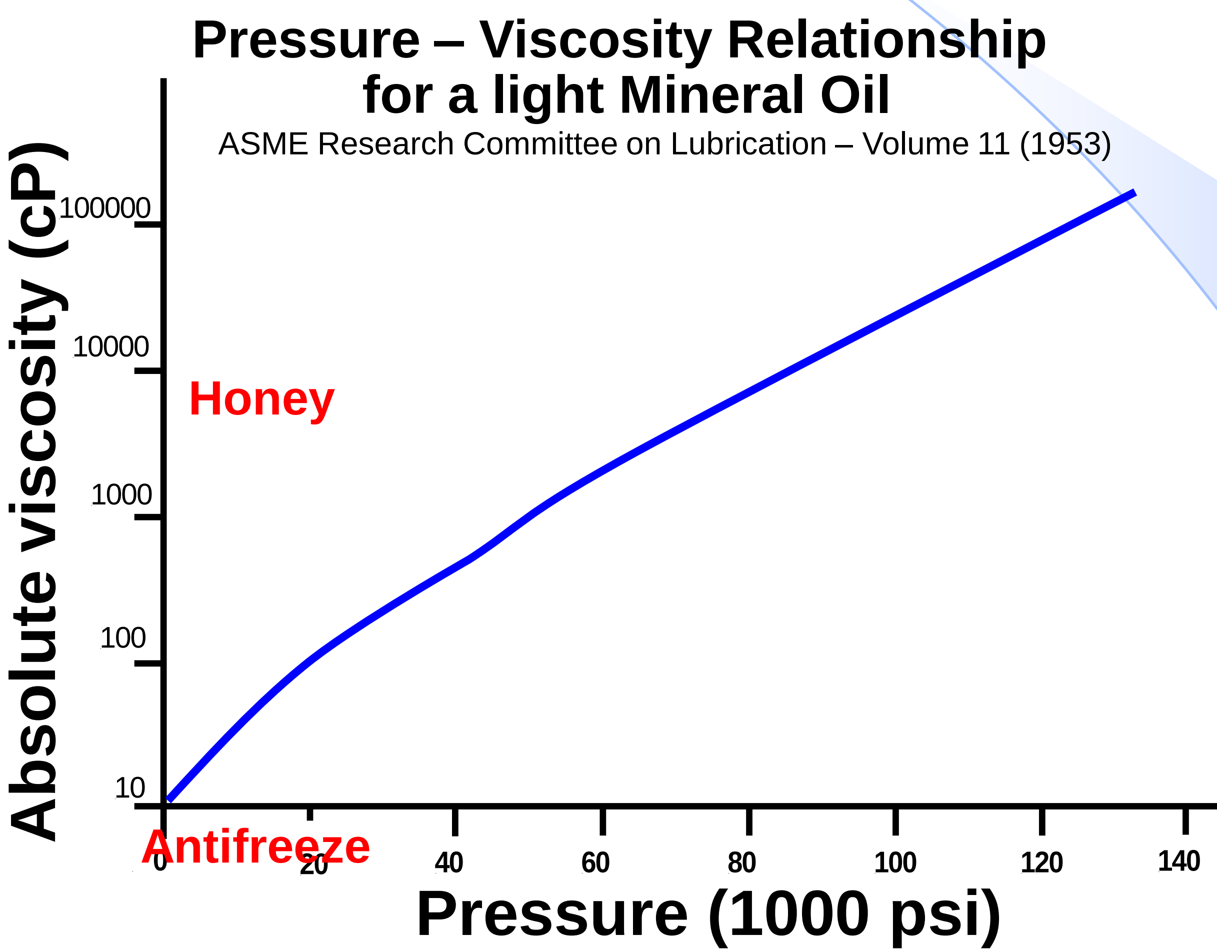
Clearance - In the range of 0.00002" to 0.00004"

Most Important Lubricant Properties - Viscosity, Cleanliness

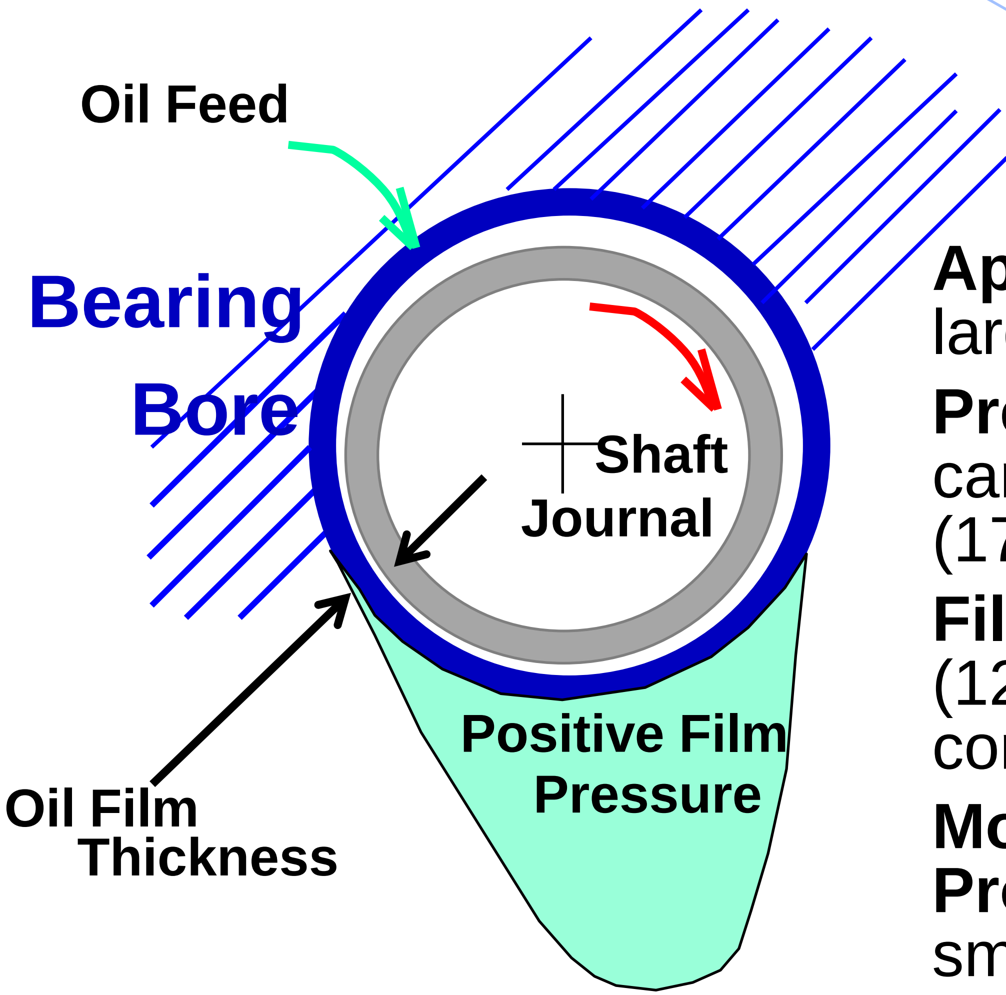
Action - Inlet zone viscosity transformation supports clearance



How Pressure Affects Viscosity



Plain Bearings



Applications - Automotive engines, large motors, generators

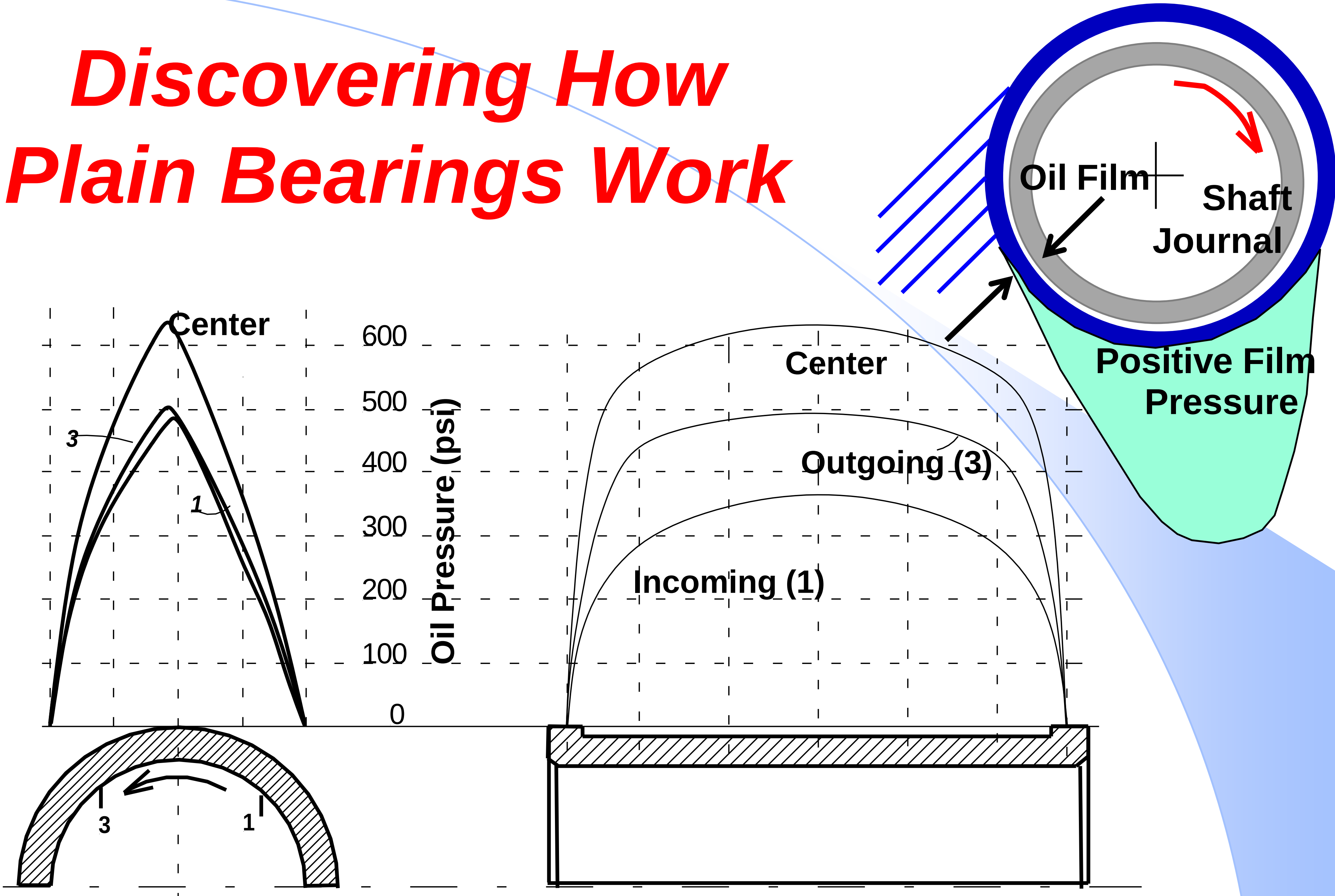
Pressures - In heavy duty diesels can range as high as 3500 psi (170kPa).

Film Thickness - 0.0005 to 0.002” (12 to 50 µm), depending on conditions

Most Important Lubricant Properties - Viscosity, contaminants smaller than film thickness

Action - Viscosity of oil swept into load zone develops pressure film

Discovering How Plain Bearings Work



This sketch is from Beauchamp Tower's original report on his experiments to understand how plain bearings work and shows the pressure in a 4" diam x 6" long journal. Kingsbury's experiments on similar devices showed the friction coefficient to be 0.0005.

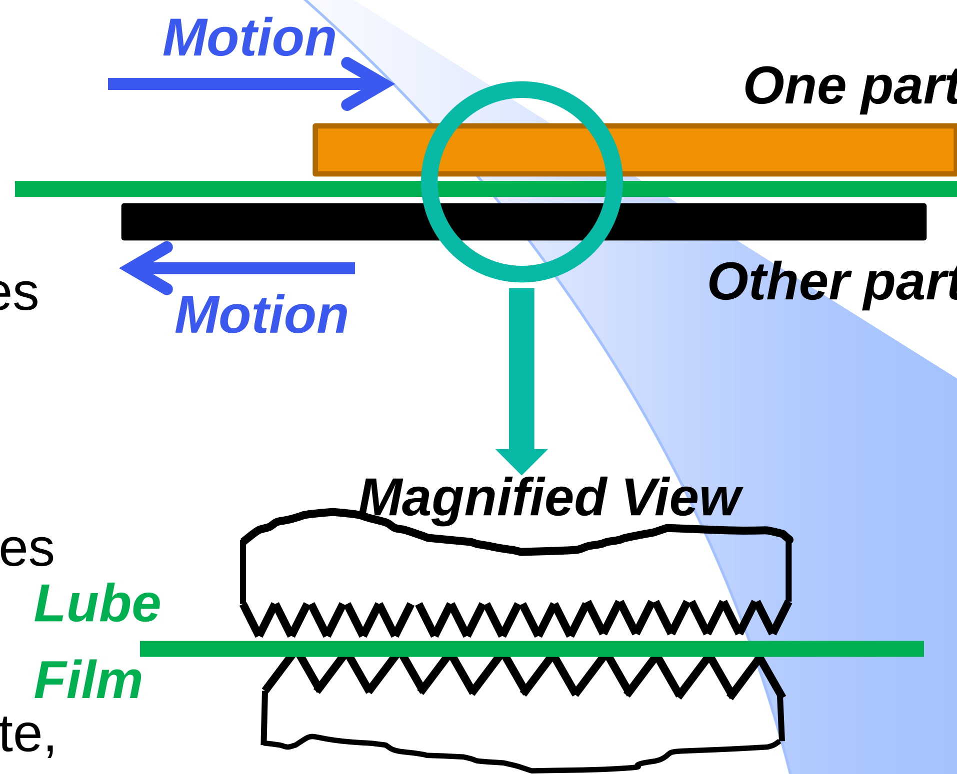
Sliding Bearing Operation

Pressures - Up to yield strength stresses on the mating parts.

Important Lubricant Properties - Film forming additives, solid particle additives.

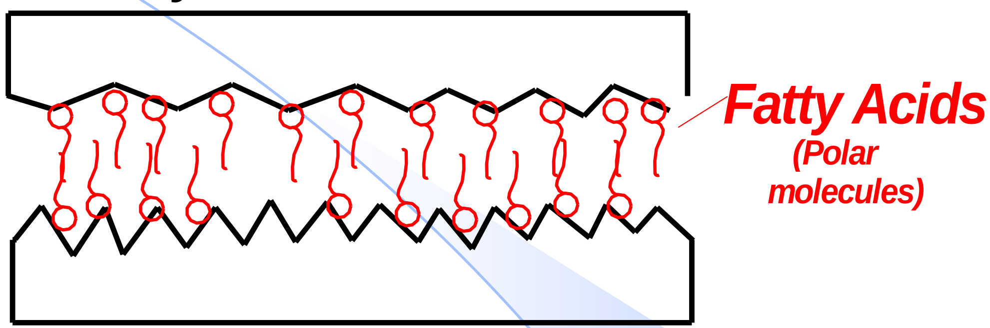
Two very different classes of Additives -

- ***AW* -** Low stress antiwear lubricants usually use fatty acids to separate pieces
- ***EP* -** High stress extreme pressure applications have two systems.
  - Contact between opposing plates causes chemical action and additives form a solid lubricant film, reducing friction between plates.
  - Solid additives, like MoS_2 or graphite, act as separators.



Sliding Bearing Operation

Low stress ***A**nti**W**ear* lubricants usually use fatty acids to separate pieces (problems above 150^0C)



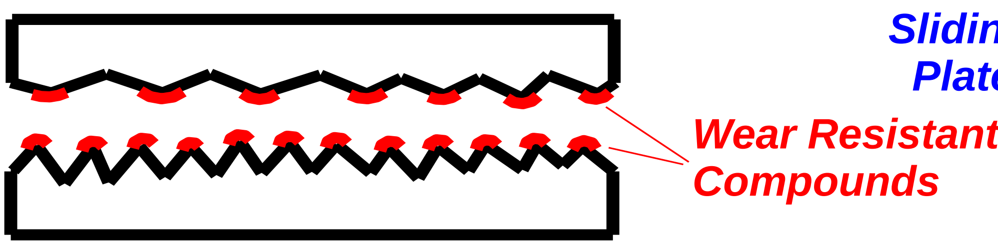
High stress ***E**xtreme **P**ressure* applications usually combine two systems:

Contact between opposing plates causes a chemical action and additives form a solid lubricant film, reducing friction.

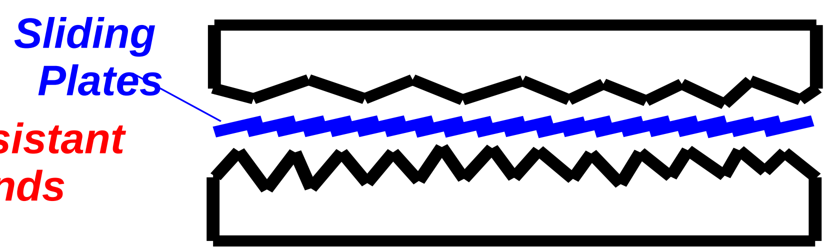
Solid additives, like MoS_2 or graphite, that act as separators.

Magnified Views of Surfaces with EP Lubricants

Chemical Reaction Additives



Solid Separating Additives



Basics of Selecting a Lubricant *(1st page)*

- What is the application? What type of action does it have to perform?
- What is the operating atmosphere?
- What are the contaminants and how severe are they?
- Is metal-to-metal contact likely? Are additives needed?
- In noise level important?

Basics of Selecting a Lubricant *(cont'd)*

- If the application is a rolling element bearing at normal speeds and loads, then viscosity is the key.
- If the application involves very heavy loads, sliding, or very slow speeds, then the key is the anti-wear additive film.
- How well can the area be sealed, i.e., would oil leakage be likely?
- Conditions such as moisture, atmospheric contamination, and a desire for long life, require special additives.

Selecting the Ball and Roller Bearing Lubricant

Lubricant properties

- Elastomer compatibility
- Oil miscibility
- Viscosity index
- Pour point
- Friction control
- AW or EP requirements
- Water stability
- Oxidation stability
- Deposit control

Operating conditions

- Housing temperature
- Humidity/moisture level
- Vibration level
- Bearing position
- Bearing type
- Speed

Once the application is known, the optimum viscosity and formulation is chosen.

Selecting the Better Lubricant - Oil or Grease?

- **OIL -** A combination of a base oil and additives
- **GREASE -** A combination of a base oil, additives, and a thickener

What percent of a typical 10W-30 is additives? **16 – 19% +/-**

What percent of an automotive gear oil is additives? **4.5 – 5.5%**

What percent of a industrial gear oil is additives? **3.5 – 4.5%**

Selecting the Better Lubricant - Oil or Grease? *(cont'd)*

- Use greases where sealing is difficult, at lower speeds, where relubrication is difficult, and where the lubricant is used to keep dirt and contamination out.
- Use oils at higher speeds, where heat transfer is needed, and in applications that are well sealed.

Making an Oil or a Grease

- OIL
  - Made up from a **base oil** plus **additives**
  - Depending on the application and the base, additives may be 20% of the total product volume.
- GREASE
  - Additives usually range from 0 to 15% of the volume.
  - Thickener usually ranges from 4 to 20% of the volume.
  - Made from a **base oil** and **additives** plus a **thickener** (sometimes called a soap).

What does "A Number 2 Grease" mean?

Many people specify grease numbers by the penetration of a dart! **[really a measure of pumpability, i.e., motility]**

NLGI Grade	Dart Penetration (0.1mm)	Consistency and typical applications
000	445-475	These are very soft greases, similar to thick
00	400-430	gear oils and are most often used on heavy
0	355-385	slow gear drives
1	310-340	#1 and #2 are the common greases used in most
2	265-295	ball and roller bearing applications. #3 is used at
3	220-250	higher temperatures and for plain bearings
4	175-205	These are "block greases" and are relatively hard,
5	130-160	with #6 being brick-like. Used in sliding applications
6	85-115	and at higher temperatures

How should we specify a grease?

1. By the application
    1. Ball bearing grease, coupling grease, multi-purpose grease, etc.
    2. By the loading conditions
2. By the “motility”, i.e., how “stiff” the grease is so we can pump it for long distances, or at low temperatures, depending on the site.

What is the Thickener for?

- The ***soap,*** or thickener usually ranges from 4 to 20% of the grease volume. It is valuable because it controls many of the grease's physical properties. However, depending on the application, the most important properties could be either the viscosity or the additives.
- In most cases, it serves as a reservoir, storing the oil and letting it slowly seep out into the areas where it is needed.
- **BUT,** in some cases we don't want the oil and thickener to separate. With those greases, the thickener holds the oil and additives in position.

What is meant by a “high temperature grease”

That refers to the “dropping point” of the thickener, the point where the thickener becomes liquid.

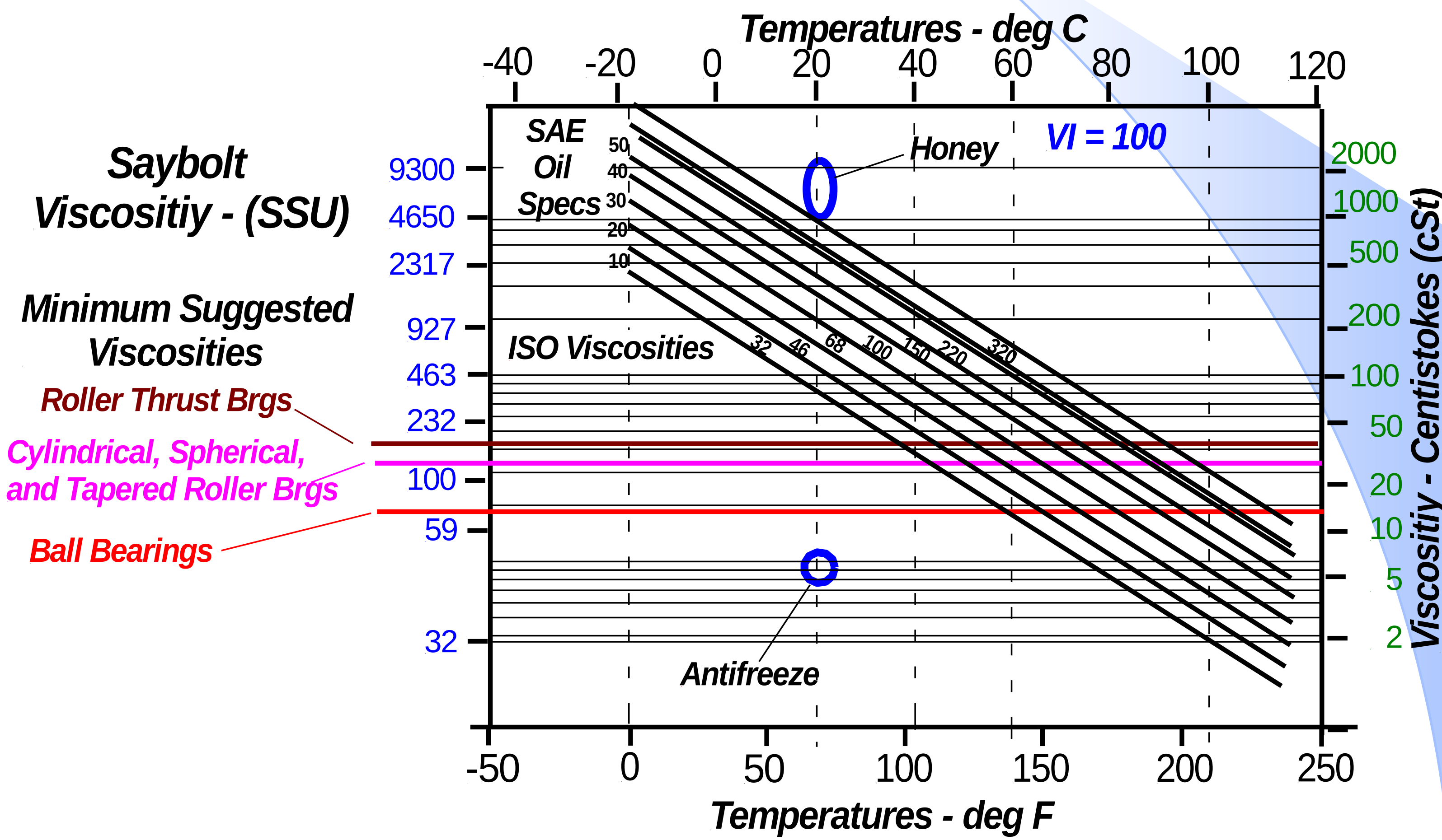
But what does that tell about the lubricating properties of the grease?

What type of oil should be used for ball and roller bearings?

Start with the proper viscosity, then select the additive package.

Selecting the Correct Oil Viscosity (Whether its an oil or a grease)

The three solid horizontal lines show the appropriate viscosity for most bearing applications. But, at very heavy loads or low speeds additional information is needed.



Important Note - **This chart does not apply below 50 rpm and it is drawn for a VI of 100.**

Viscosity Conversions

Viscosity and Grade Comparisons		
ISO Viscosity Grade	Saybolt Viscosity @ 100^0 F	AGMA Gear Lube Spec. (including EP)
46	215	AGMA 1
68	315	AGMA 2
100	465	AGMA 3
150	700	AGMA 4
220	1000	AGMA 5
320	1500	AGMA 6
460	2150	AGMA 7
680	3150	AGMA 8

Notes:

1. Approximate conversion   cSt x 4.65 = SSU
2. AGMA no longer publishes these gear specifications but you may see them on nameplates.

What Happens when the Viscosity isn't Adequate?

If the film isn't separating the two pieces, they tend to deteriorate rapidly because of increased fatigue forces or immediate welding damage.

Sometimes, an alternate to this is to have **boundary lubrication additives** that form protective films when the initial contact occurs.

Why do Lubricants Require Replacement?

- They become contaminated with foreign material.
- Their additives are used up.
- They leak out.
- Some components evaporate.
- ***IMPORTANT POINT -*** *Arrhenius' Rule states that "For every 10^0 C (approximately) temperature increase the rate of a chemical reaction will double."* From a practical point this means that for every 10^0C (18^0F) increase in temperature, a lubricant's life is halved.

Q. *What is a Synthetic?* A. *A Very Confusing Situation.*

- There are still arguments about the formal definition.
- Traditionally, crude oil has been distilled to make a base oil of a given viscosity. The source of the crude determined the viscosity index (VI) of the base oil produced.
- True synthetic oils (PAO, PAG's, etc.) are made with molecules of a given construction and usually have better VI and lubricating properties than conventional oils.
- About 35 years ago Chevron released a new process for distilling (called hydrocracking) that gave much closer control. These **UCBO's** (unconventional base oils) or **Group II+** base oils are legally considered synthetics, are very close to true synthetics in many of their performance properties, and are much less expensive than PAO's and PAG's. (Other suppliers of these UCBO's include PetroCanada, Conoco, Pennzoil…)

Major Differences between Conventional and Synthetic Lubes

- Synthetics are tailored to meet specific needs.
  - Good high temperature oxidation resistance.
  - Good low temperature flow characteristics.
  - Relatively low volatility.
- Synthetics will be more costly to use if the user doesn't take advantage of superior properties.
- There are specific applications where synthetics produce better results (and vice versa).

Why do Synthetics or UCBO's have an Advantage?

- Their basic VI and volatility properties are better than conventional base oils.
- ***Therefore***, they need fewer additives and less of those additives.
- ***As a result***, there is less to degrade with time and temperatures.
- So the oils last longer - before contamination becomes a problem.
- Also, in some cases they have less internal friction and run cooler and contribute about a 1.5% energy savings.
- ***But they really don't perform better as lubricants in most (probably 97%) applications.***

Some synthetic lubes

all liquids with a relatively narrow range of molecular weights

- ***PAO*** – polyalphaolefins – made by the Ziegler Natta process where decene ($C_{10}H_{20}$) flows over a titanium based catalyst to form alpha olefins. PAO’s are hydrogenated olefin oligomers manufactured by the catalytic polymerization of linear alpha olefins
- ***PAG*** - polyalkylene glycols – several different kinds, all of which are copolymers of either ethylene oxide (EO) or propylene oxide (PO). There are over 100 different PAG chemistries that are used in lubes, and some are water soluble while others are oil-soluble. Generally much lower traction coefficients than PAO’s or mineral oils.
- ***Polyol Esters*** - “Polyol esters” –an abbreviation for “neopentyl polyol esters” which are made by reacting monobasic acids with polyhedric alcohols having a neopentyl structure. Good high temperature lubricity and viscosity. Commonly used in refrigerant oils.
- ***Also a***lkyl aromatics***,*** esters of dibasic acids, phosphoric acid esters, silicones, silicate esters, fluorocarbons, and lots of words I’m not familiar with.

For what applications do synthetics provide superior lubricant films -

- Some air compressors
- Some hot and heavily loaded bearings
- High friction applications
- Refrigeration systems

What does the future hold for lubricant changes?

- New additives that will do the job will fewer environmental problems (phosphorus in engine oils)
- New ashless additives that will provide better wear and oxidation resistance with fewer deposits.
- More emphasis on surface preparation and solid lubricants