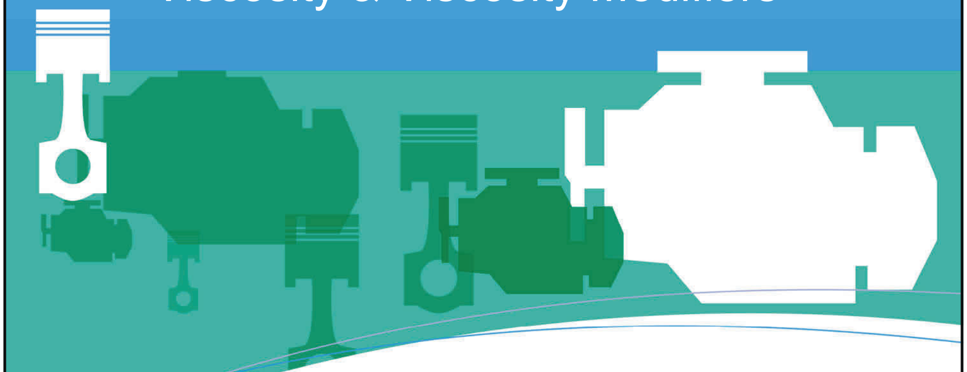
Performance you can rely on.

Viscosity & Viscosity Modifiers



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Outline

- Viscosity
  - Definition & Terminology
  - Temperature Dependence
- Viscosity Modifiers
  - Function
  - Thickening Efficiency
  - Shear-Thinning
  - Types/Chemistry
- Pour Point Depressants
- SAE Viscosity Grades
- Appendix
  - Viscosity measurement methods

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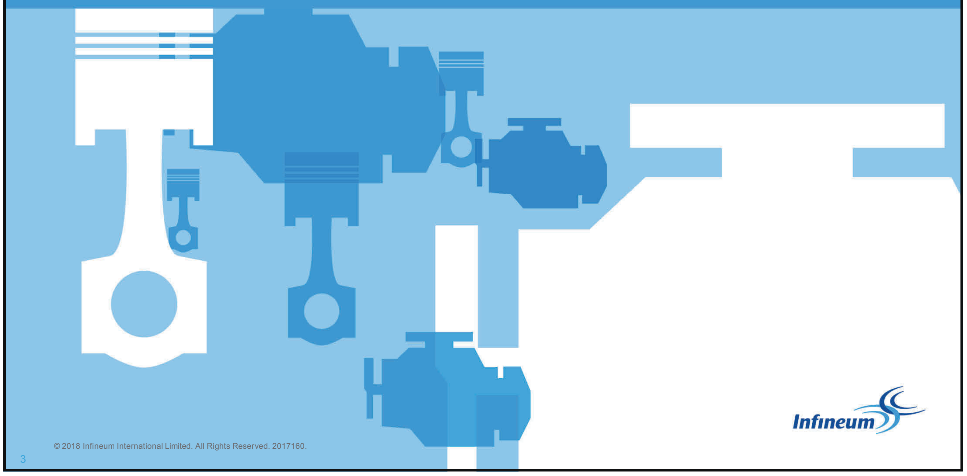
Viscosity



Viscosity

- Dynamic viscosity is resistance to flow of a fluid
- Defined as shear stress divided by shear rate (how hard you push it divided by how fast it slides)
  - Units of dynamic viscosity:
    - Pascal seconds (Pa-s)
    - mPa-s = 1cP (CentiPoise)
- Dynamic viscosities are usually measured under high shear conditions:
  - For example, the cone on plate or cylinder viscometer
- Kinematic viscosity is the dynamic viscosity divided by the fluid density.
  - The physical principle of measurement is based on the rate at which a fluid flows under gravity through a capillary tube.
  - Usually measured under low shear conditions.
  - Units of kinematic viscosity:
    - mm^2/s = CentiStoke (cSt)
- Famous scientists who contributed to viscosity fundamentals

What is the optimal viscosity?

- Metal on metal contact leads to high energy losses and surface wear
- Oil film between metal surfaces reduces energy losses
  - Oil provides less resistance to movement than metal
- Sufficient viscosity is needed to form the film
- Viscosity should be high enough to form the protective film, but low enough not to give excessive energy losses within the fluid

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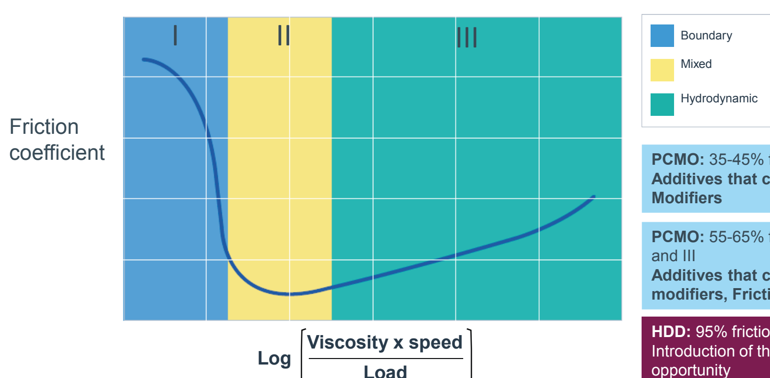
Stribeck curve



PCMO: 35-45% frictional losses in I
Additives that can help: Friction Modifiers

PCMO: 55-65% frictional losses in II and III
Additives that can help: Viscosity modifiers, Friction Modifiers

HDD: 95% frictional losses in III
Introduction of thinner fluids is a big opportunity
Additives that can help: Viscosity modifiers

Viscosity modifiers and friction modifiers can be used in a complementary fashion in properly formulated engine oils to reduce friction because they operate in different lubrication regimes, as noted in the Stribeck Curve.

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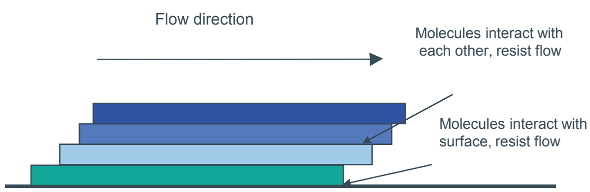
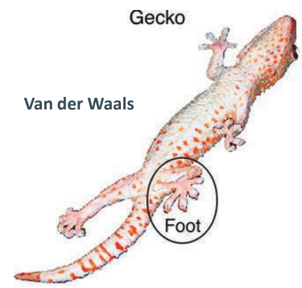
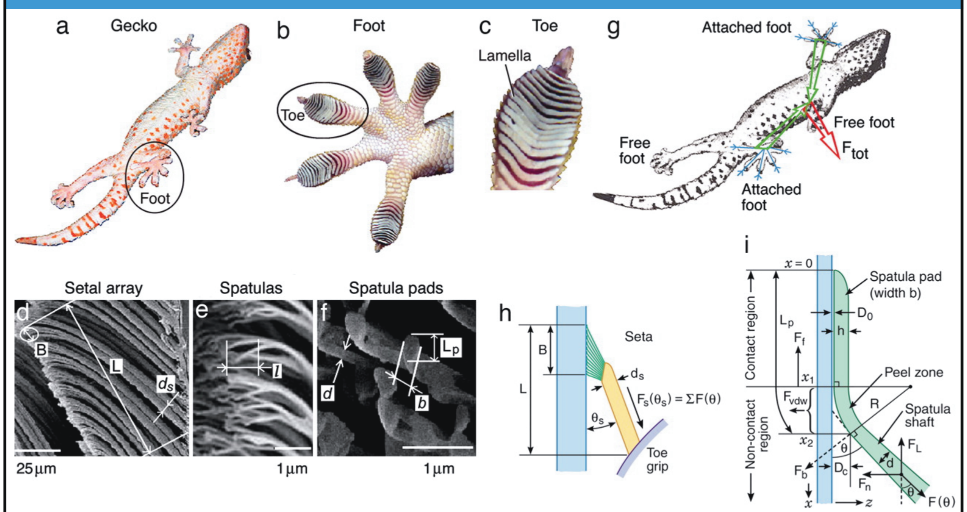
Molecular origins of viscosity

- Molecules in adjacent layers of oil interact, preventing layers from sliding past each other
- The higher the interaction the higher is the resistance to the flow (viscosity)
- Interacting Forces:





Gecko Toe Adhesion



Yu Tian, Noshir S. Pesika, Hongbo Zeng, Kenny Rosenberg, Boxin Zhao, Paula McGuiggan, Kellar Autumn, Jacob N. Israelachvili. *PNAS* **103** (2006) 19320-19325

Viscosity of materials

Substance	Viscosity at room temp (mPa-s or cP)
Ketchup	100,000
VM Concentrate	40,000
Molasses	8,000
Maple syrup	3,000
Motor oil (SAE 8 – SAE 40 grades)	25 - 350
Olive oil	80
Group III base oil 4 cSt	45
Mercury	2
Water	1
Gasoline	0.5
Acetone	0.3
Air	0.018

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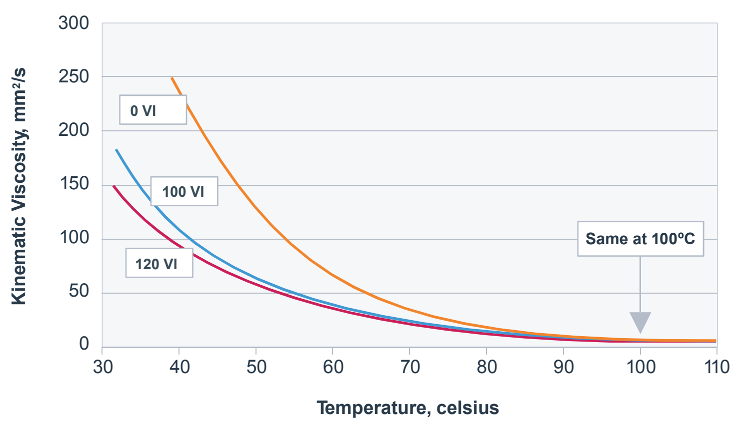
Viscosity index



Viscosity Index (VI) defines the viscosity relationship with temperature.

- The Viscosity of low VI oils change significantly with temperature
- The Viscosity of high VI oils changes much less with temperature

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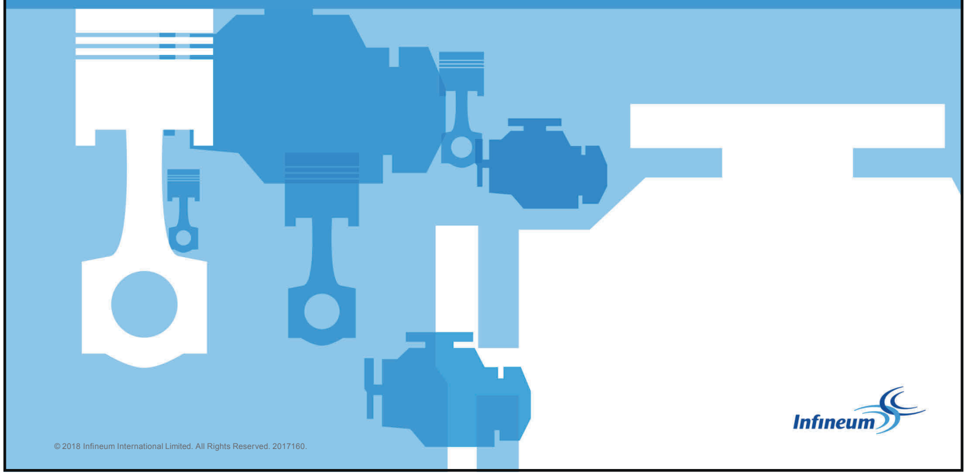
Viscosity modifiers



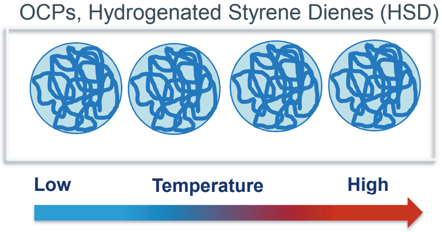
Viscosity modifiers

- Viscosity modifiers (VM) are used to reduce the influence of temperature on the viscosity of lubricants
  - Also known as Viscosity Index Improvers (VII)
- Viscosity modifiers in crankcase lubricants are polymers
- VM's are used in most engine oils and many transmission fluids

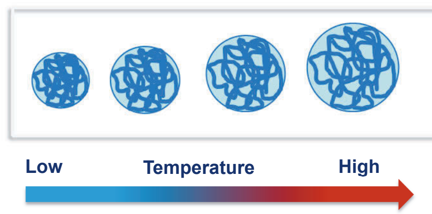
Viscosity modifiers

- Polymeric Viscosity Modifier occupies large volume of solution
- Viscosity modifier increases viscosity proportionally to volume that polymer occupies
- Volume of the majority of viscosity modifiers is almost independent of temperature

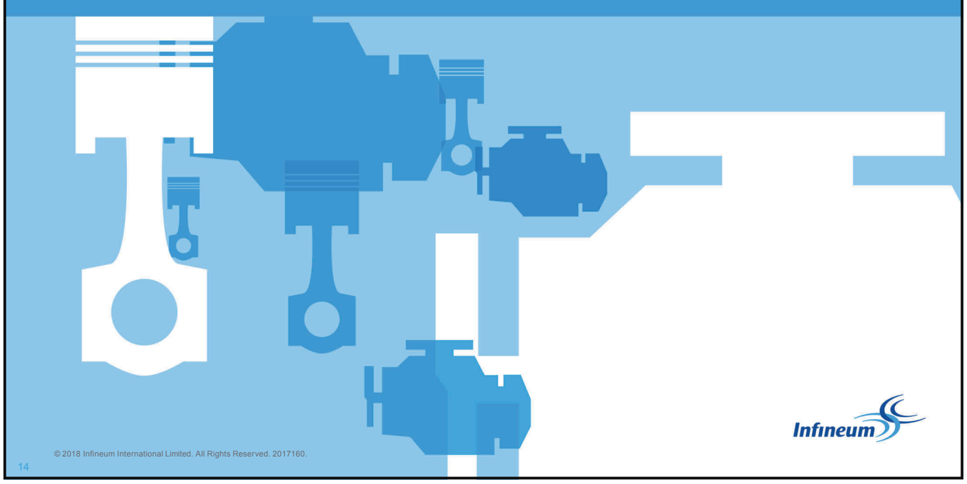
OCPs, Hydrogenated Styrene Dienes (HSD)



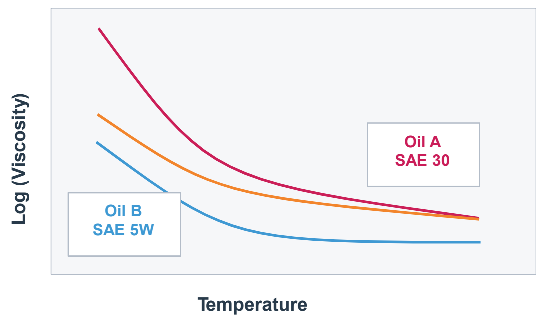
PMAs, temperature sensitive OCPs and HSDs



Function of viscosity modifiers

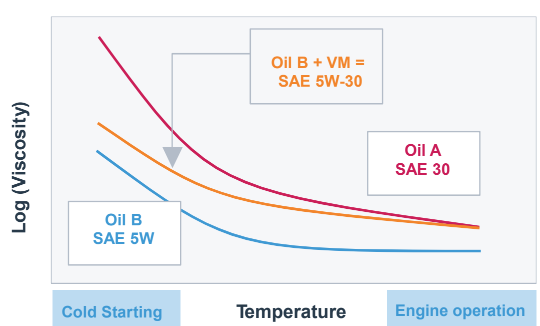


Function of viscosity modifiers



- Base oil viscosity has strong temperature dependence:
- First described in 1920s and now more precisely in ASTM D341
- Thinner base oils (Oil B) provide good low temperature properties, but cannot provide protection at high temperatures
- Thicker base oils (Oil A) provide protection at high temperatures, but have insufficient pumpability at low temperatures

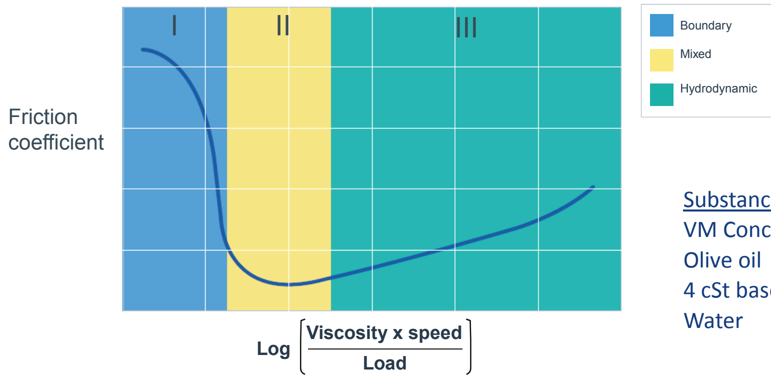
Function of viscosity modifiers



- VM adds viscosity to thinner oil at both high and low temperatures proportionally to baseoil viscosity at the particular temperature
- VM added viscosity does not have strong dependence on temperature
- Reduces final oil temperature dependence
- Multigrade oils (SAE xW-xx) provide engine protection at both high and low temperatures through use of viscosity modifiers

Function of viscosity modifiers - Demo

- Effect of Viscosity and VM Polymer on Friction – Stribeck Curve



Substance	Visc at Room T (cP)
VM Conc.	40,000
Olive oil	80
4 cSt baseoil	45
Water	1

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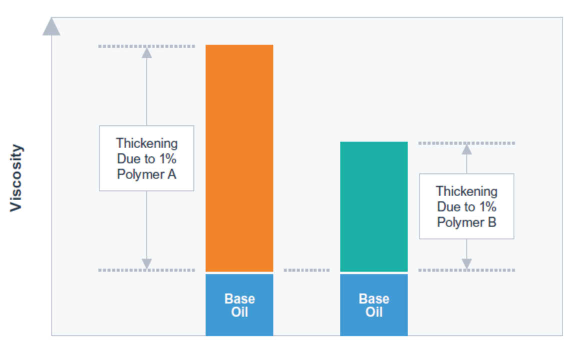
Thickening efficiency



- Thickening Efficiency or TE is the amount of viscosity increase per % polymer
- TE is highly dependent on Molecular Weight and chemistry
  - Higher MW = Higher TE
  - Less Branching = Higher TE
  - Better match of VM polarity to base oil polarity = Higher TE

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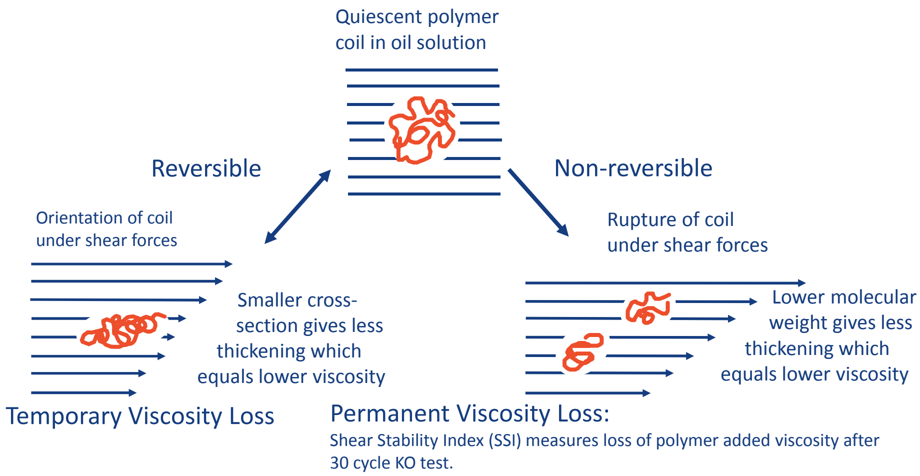
Shear-thinning: Temporary & Permanent Viscosity Loss



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Shear stability index (SSI) (permanent viscosity loss)

- Shear Stability Index (SSI) measures loss of polymer added kinematic viscosity after 30 cycles in Kurt Orbahn
- The higher the SSI the more viscosity loss upon oil shearing
- SSI is usually measured in a reference oil that represents polymer behavior in SAE 15W-40 grade
- SSI depends on polymer chemistry, molecular geometry and molecular weight
  - Higher MW = less shear stable VM

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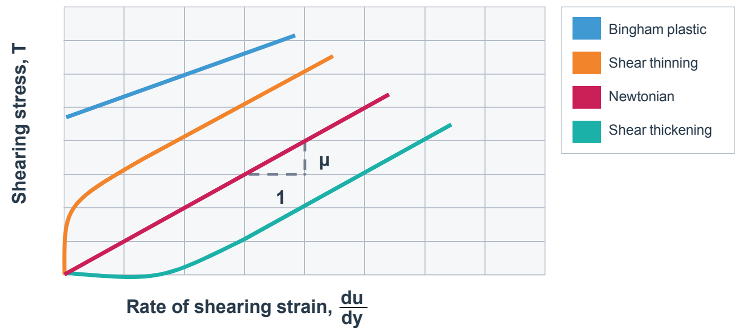
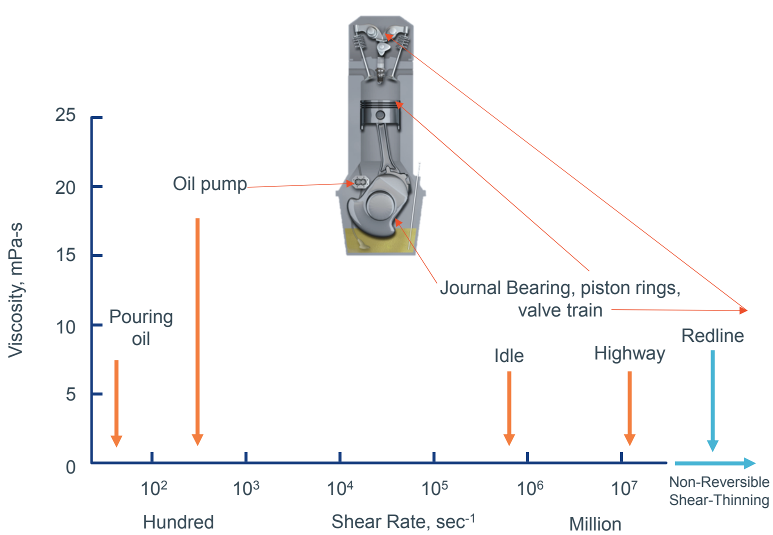
Newton's law & shear thinning (temporary viscosity loss)

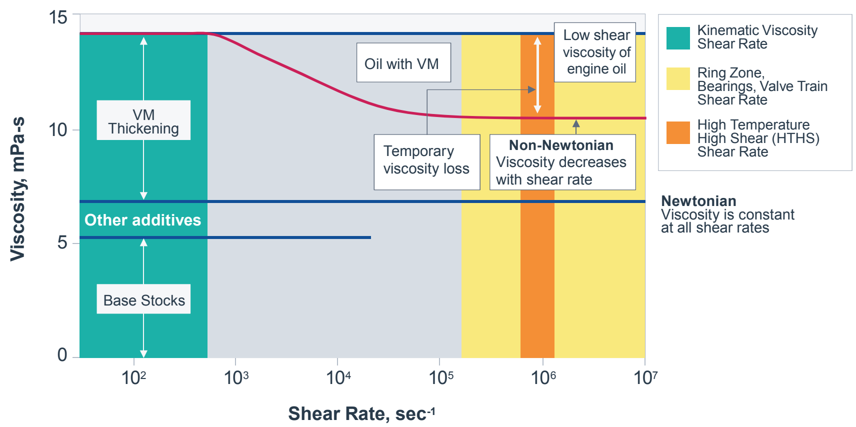


- Newton's Law of Viscosity: viscosity = shear stress / shear rate
- Newtonian Fluids = viscosity is a constant; does not change with shear stress or shear rate
- Fluids that do not obey this are called Non-Newtonian
- The most common type is Shear-Thinning
  - Viscosity decreases with increasing shear rate
  - Viscosity modified fluids fall into this category

Typical shear rates



Shear rate & shear-thinning



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Viscosity modifier types

- Common types
  - Ethylene-Propylene Co-polymer (OCP)
    - Semi-crystalline
    - Amorphous
  - Hydrogenated Styrene-diene Co-polymer (HSD)
  - Polymethacrylate (PMA)
- Factors that need to be considered when selecting VM
  - Cost to achieve required thickening (Cost vs. TE)
  - Shear Thinning Properties
  - Low Temperature Properties
- Other performance harms/credits

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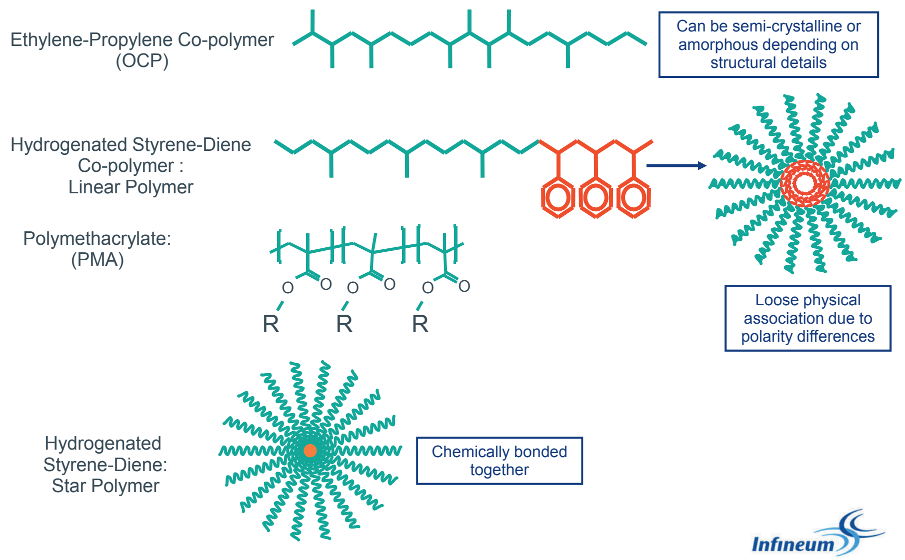
Viscosity modifier chemistry



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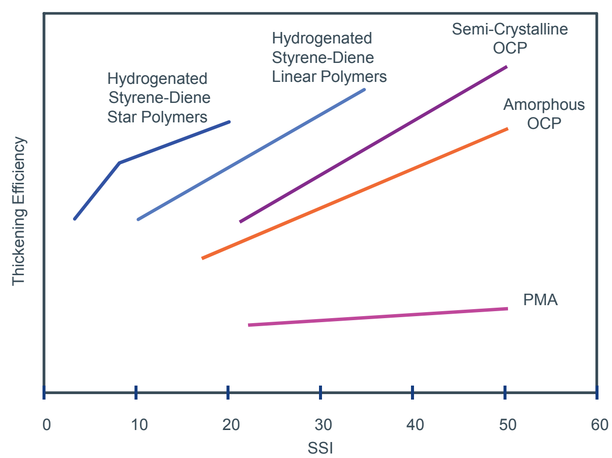
Performance comparison TE vs. SSI



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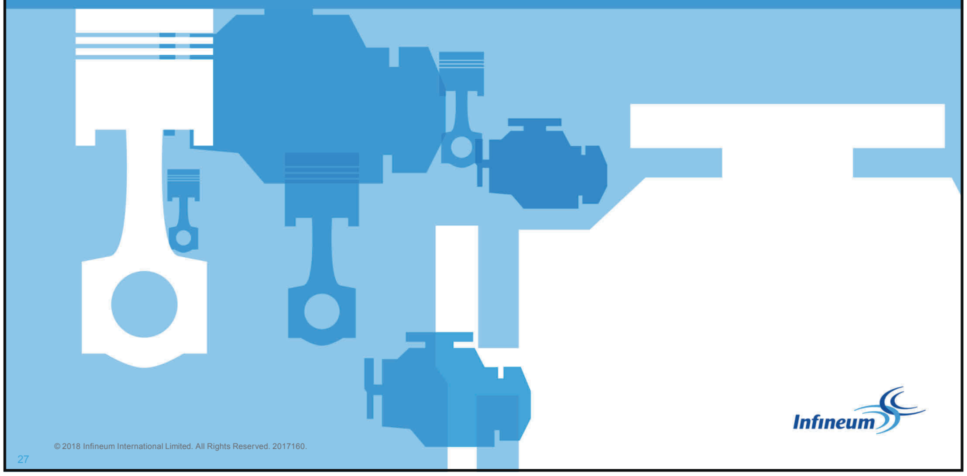
Pour point depressants



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Pour point depressants

- Pour Point Depressants
  - Commonly referred to as PPDs
  - Also know as Lube Oil Flow Improvers (LOFIs)
- Break up regularity of wax crystals
  - Prevent large crystal sheets from forming
  - Encourage small crystals - easier flow
  - Minimize low-temperature viscosity and yield stress
- Types:
  - Fumarate Vinyl Acetates (FVA)
  - Polymethacrylates (PMA)

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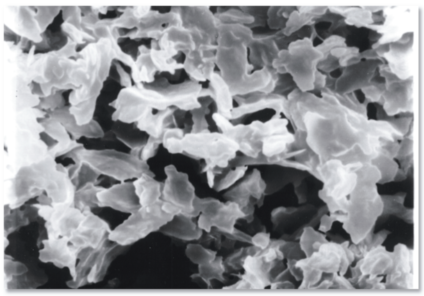
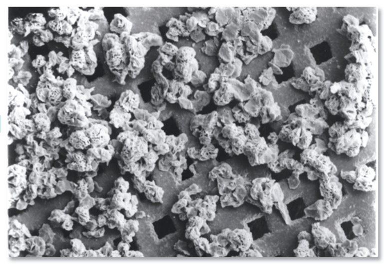
Wax crystal modification by LOFI



50 micron

- Wax crystals can cause the most serious type of engine problem
- Engines can start but the oil does not flow, leading to catastrophic engine failure

+ LOFI



50 micron

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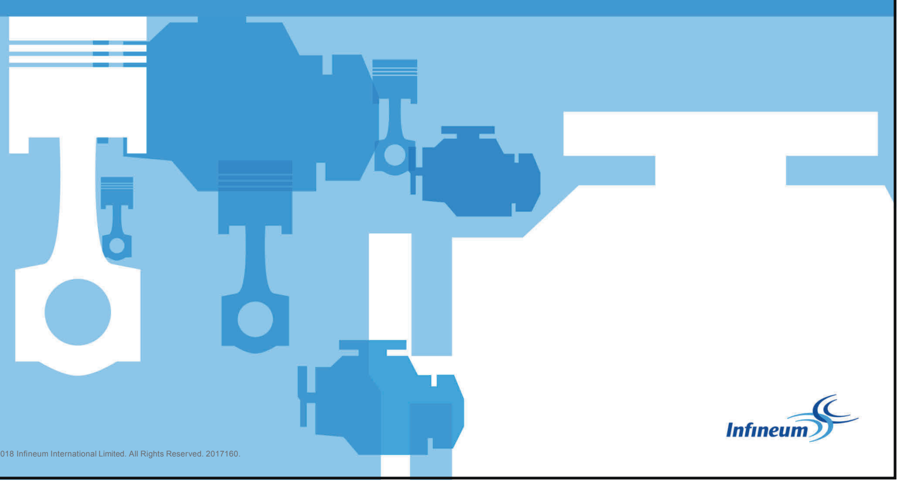
SAE viscosity grades



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SAE J300 engine oil viscosity grades (issued January 2015)

SAE Grade	CCS mPa-s, Max	MRV mPa-s, Max w/No Yield Stress	Kinematic Viscosity at 100 °C mm²/s Min	Max	HTHS @ 10^6 Sec^{-1} at 150 C mPa-s, Min
0W	6200 at -35°C	60 000 at -40°C	3.8	–	–
5W	6600 at -30°C	60 000 at -35°C	3.8	–	–
10W	7000 at -25°C	60 000 at -30°C	4.1	–	–
15W	7000 at -20°C	60 000 at -25°C	5.6	–	–
20W	9500 at -15°C	60 000 at -20°C	5.6	–	–
25W	13000 at -10°C	60 000 at -15°C	9.3	–	–
8	–	–	**4.0**	**<6.1**	**1.7**
12	–	–	**5.0**	**<7.1**	**2.0**
16	–	–	**6.1**	**<8.2**	**2.3**
20	–	–	**6.9**	<9.3	2.6
30	–	–	9.3	<12.5	2.9
40	–	–	12.5	<16.3	3.5(1)
40	–	–	12.5	<16.3	3.7(2)
50	–	–	16.3	<21.9	3.7
60	–	–	21.9	<26.1	3.7

(1) For 0W, 5W, 10W Multigrades – Changed from 2.9 in 11/2007
(2) For 15W, 20W, 25W Multigrades and SAE 40 Grade

Previously 5.6

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Viscosity measurement methods

Temp	Shear	Performance	Instrument	ASTM Method
High	Low	Oil Consumption Quality Control	Kinematic Viscometer	D 445
Low	High	Cold Starting	Cold Cranking Simulator (CCS)	D 5293
Low	Low	Cold Pumping	Mini-Rotary Viscometer (MRV)	D 4684
High	High	Wear/Fuel Economy	Tapered Bearing Simulator (TBS) Tapered Plug Viscometer (TPV) Multi-Cell Capillary (MCC)	D 4683 D 4741 D 5481

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SAE viscosity grades

'Summer' Grade

60	0W-60	5W-60	10W-60	15W-60	20W-60	25W-60
50	0W-50	5W-50	10W-50	15W-50	20W-50	25W-50
40	0W-40	5W-40	10W-40	15W-40	20W-40	25W-40
30	0W-30	5W-30	10W-30	15W-30	20W-30	25W-30
20	0W-20	5W-20	10W-20	15W-20	20W-20	
16	0W-16	5W-16				
12	0W-12					
8	0W-8					
	0W	5W	10W	15W	20W	25W

'Winter' Grade

Straight Grades

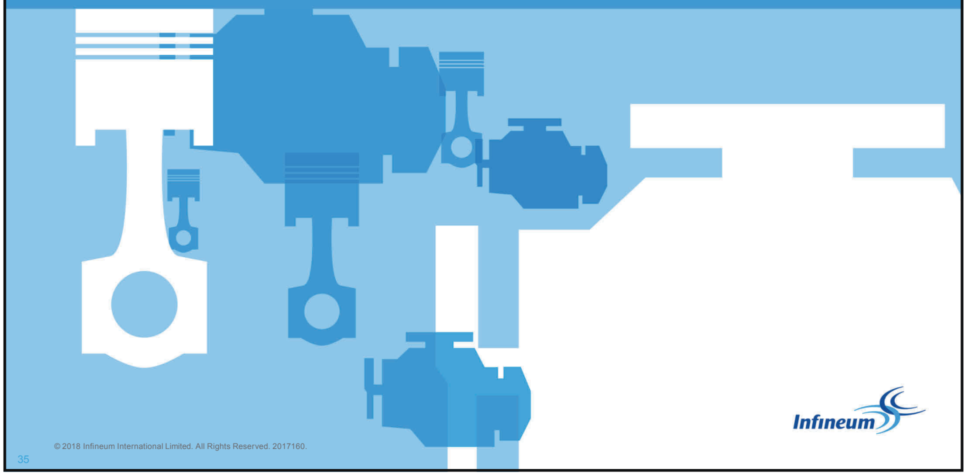
Some common viscosity grades for engine oils

•SAE 0W-X grades typically need synthetic base stocks

SAE J300 engine oil viscosity grades

- Correct
  - SAE 10W-30
- Incorrect
  - 10W-30
  - SAE 10W/30
  - SAE 10W30
  - SAE 10w-30
- Labeling
  - Must label as the lowest 'W' grade
    - An oil that meets 5W also meets 10W, 15W, etc.
  - Oils with VM must be labeled as Multigrades
- Need to take care with CCS and KV100 labelling as there is overlap between the SAE grades

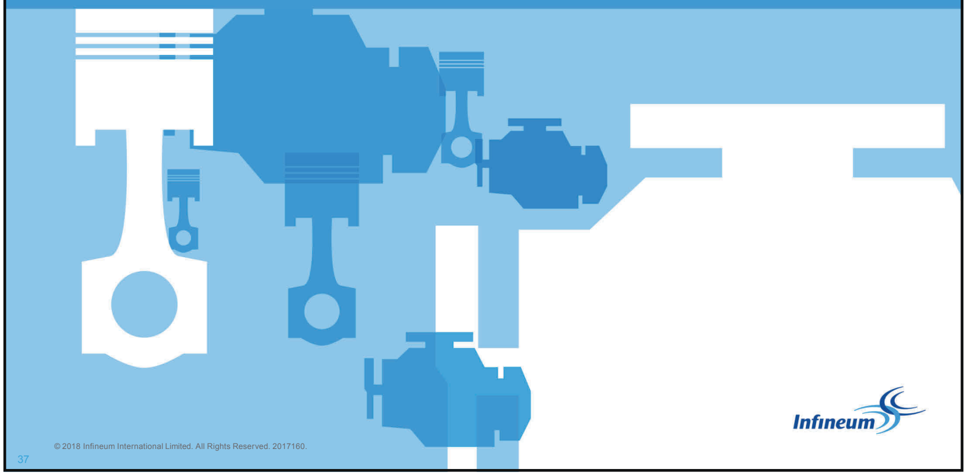
Summary



Summary

- Viscosity is a measure of a fluid's resistance to flow
  - It depends strongly on temperature
  - And it can depend on shear rate
- Viscosity modifiers in lubricants:
  - Are used to reduce the influence of temperature on lubricant viscosity
  - Chemical structure and molecular weight affect performance and efficiencies
  - Exhibit temporary and permanent viscosity loss due to shear
  - Three common types: OCPs, Hydrogenated Styrene-diene Co-polymer, PMAs
  - Oil formulators must balance viscometric requirements, engine performance and cost
- Viscosity grades are defined by SAE J300
  - *"Oils which are formulated with polymeric viscosity index improvers for the purpose of making them multiviscosity-grade products are non-Newtonian and must be labeled with the appropriate multiviscosity grade".*
    Source: SAE J300

Appendix: viscosity measurement methods



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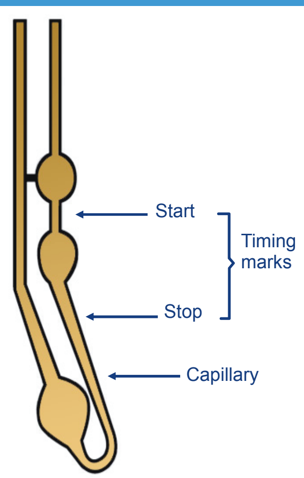
Kinematic viscosity



- Kinematic viscosity = viscosity/density
- Principle
  - Measure time for known volume to flow through capillary tube
    - Driving force: gravity (mass of fluid)
    - Low shear rate
  - Units
    - mm^2/s
    - CentiStokes = cSt (discouraged)
    - Saybolt Universal Seconds (SUS) (obsolete)

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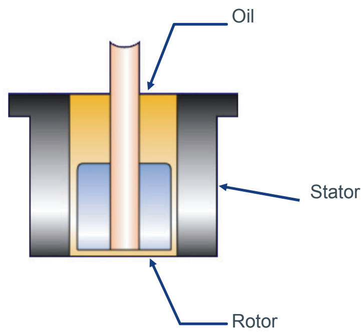
Performance you can rely on.

Cold cranking simulator

- Rotor/stator system

CCS cross-section



- Viscosity range - 500 to 200,000 mPa-s
- Shear rates - 104 to 106 sec-1
- Shear stress - 50,000 Pa

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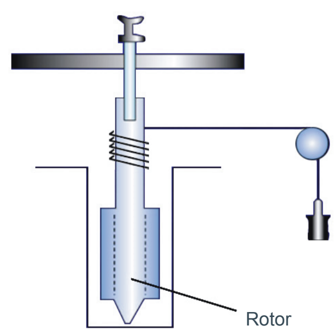
Performance you can rely on.

Mini-rotary viscometer

- Low shear rate/shear stress measurement
- Measurements
  - Yield stress
    (min. stress to cause flow)
  - Viscosity @ 525 Pa stress)
- Relationship to pumpability
  failure mechanism
  - Yield stress/air-binding
  - Viscosity/flow-limited



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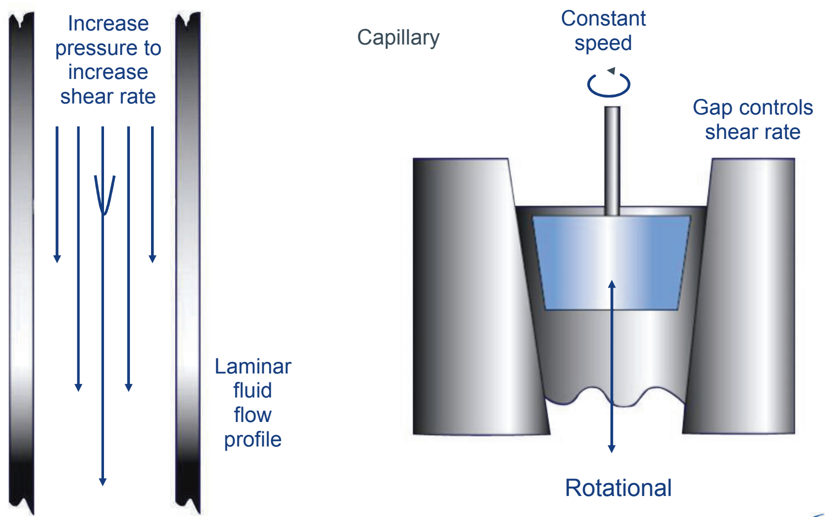
High temperature high shear



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