Infineum

Viscosity and Viscosity Modifiers

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Outline

1. **Viscosity**
   - Definition & Terminology
   - Temperature Dependence
2. **Viscosity Modifiers**
   - Function
   - Thickening Efficiency
   - Shear-Thinning
   - Types/Chemistry
3. **Pour Point Depressants**
4. **SAE Viscosity Grades**
5. **Summary**

1. 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

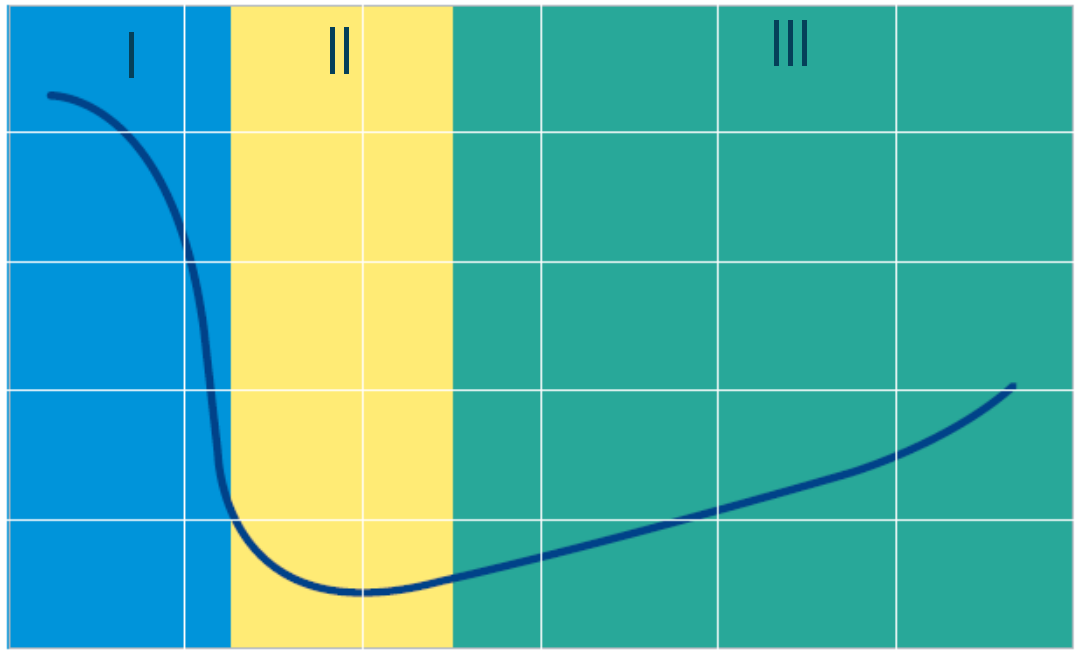
- The physical principle of measurement is based on the rate at which a fluid flows under gravity through a capillary tube.
- Usually measured under low shear conditions.
- Units of kinematic viscosity: mm^2/s = CentiStoke (cSt)

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

Stribeck curve



Boundary

Mixed

Hydrodynamic

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

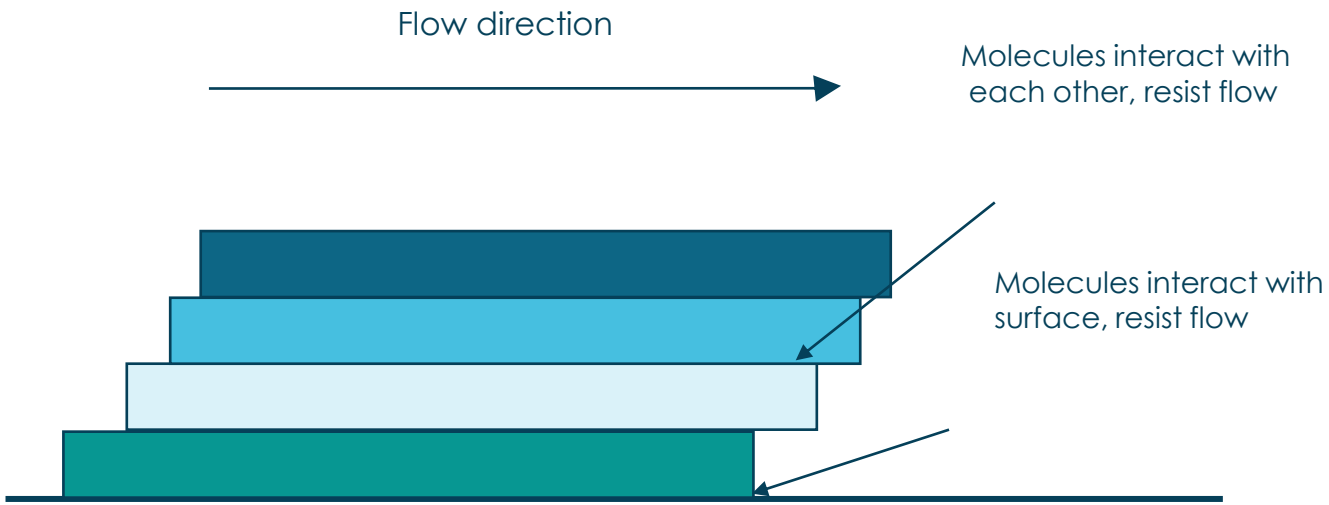
Introduction of thinner fluids is a big opportunity

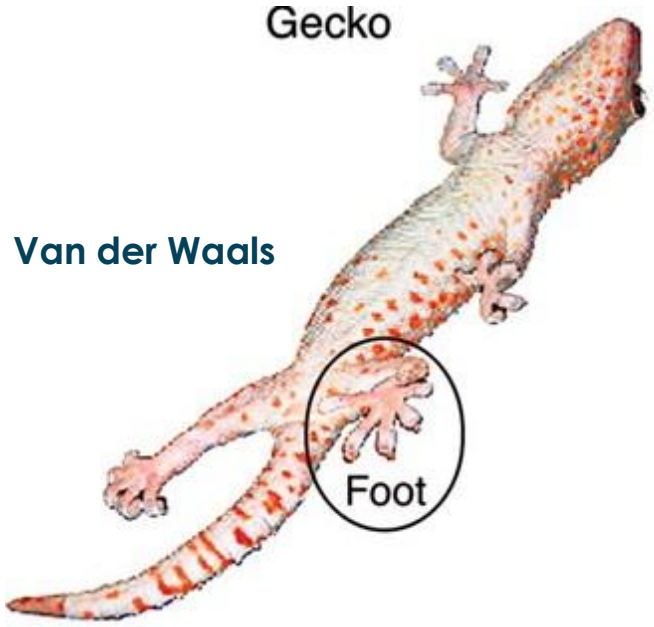
Additives that can help: Viscosity modifiers

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.

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:

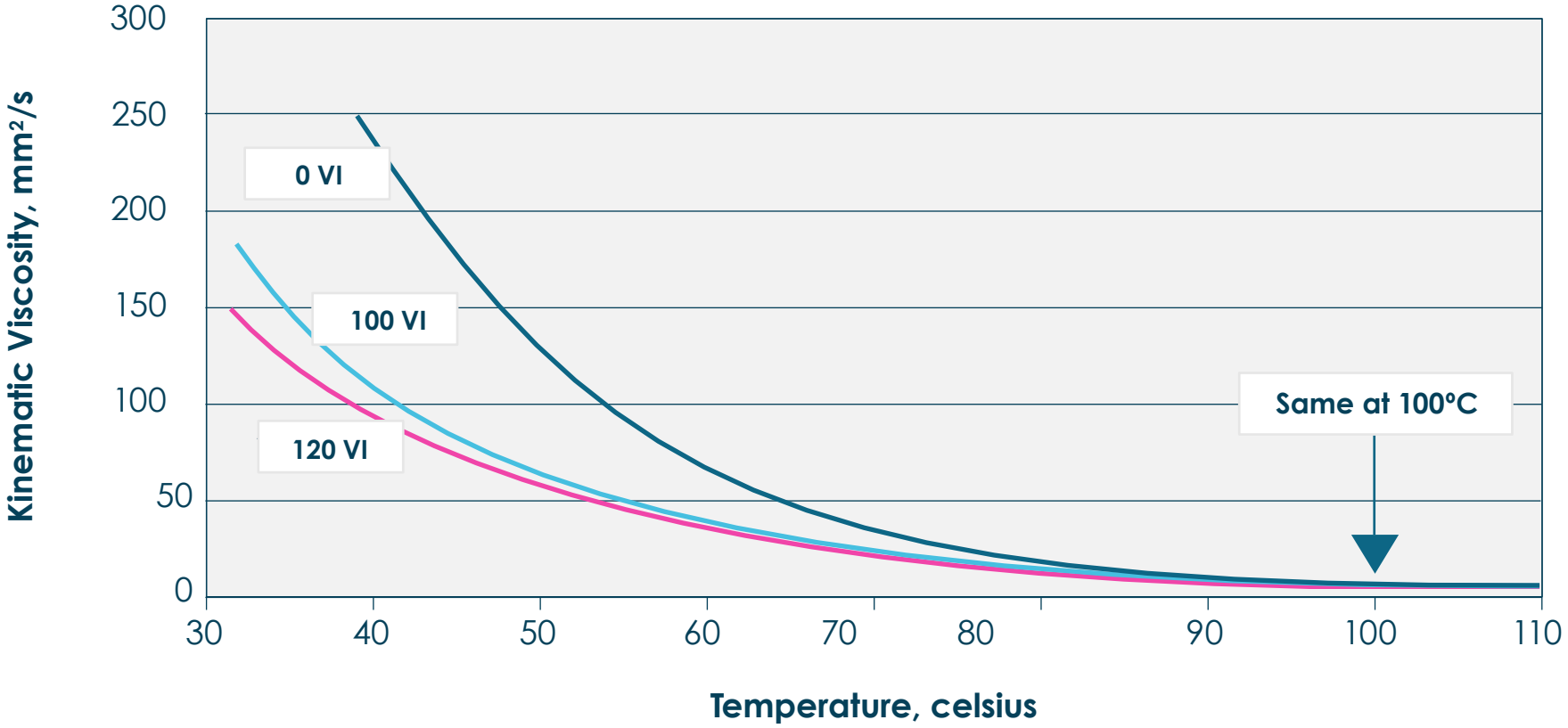




Viscosity of materials

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

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

2. Viscosity modifiers

Viscosity modifiers

1

Viscosity modifiers (VM) are used to reduce the influence of temperature on the viscosity of lubricants

Also known as **Viscosity Index Improvers (VII)**

2

Viscosity modifiers in crankcase lubricants are **polymers**

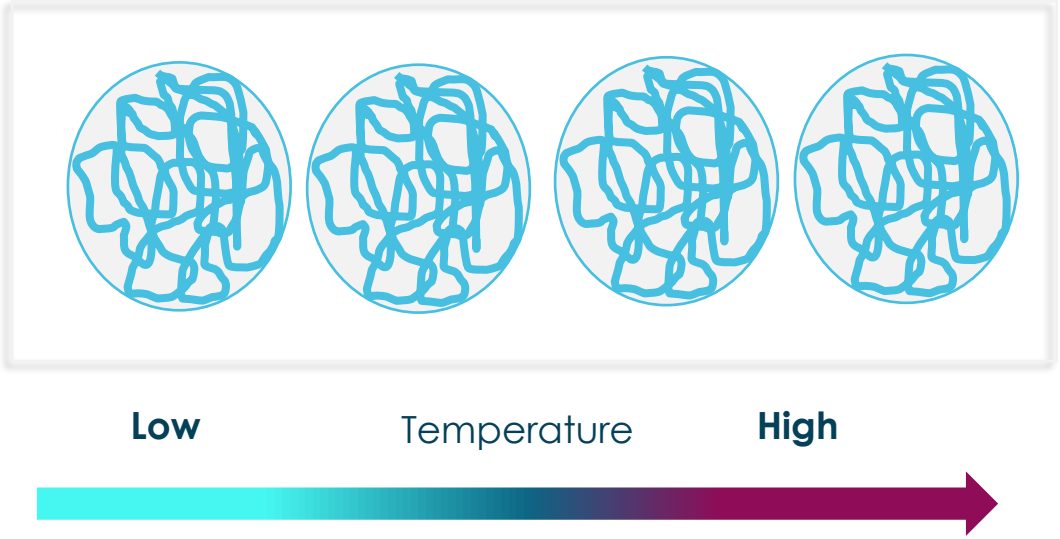
3

VM's are **used in most engine oils and many transmission fluids**

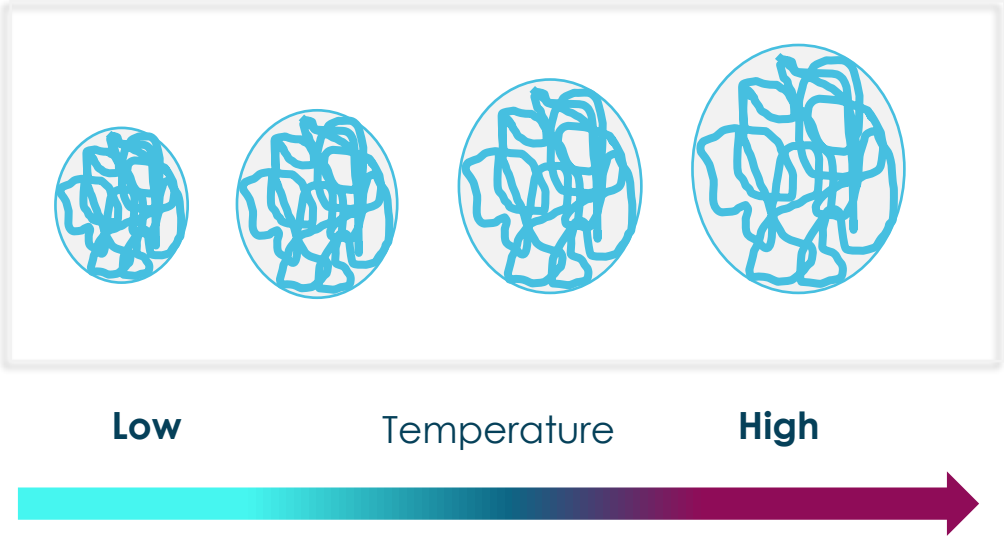
Viscosity modifiers

- **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)

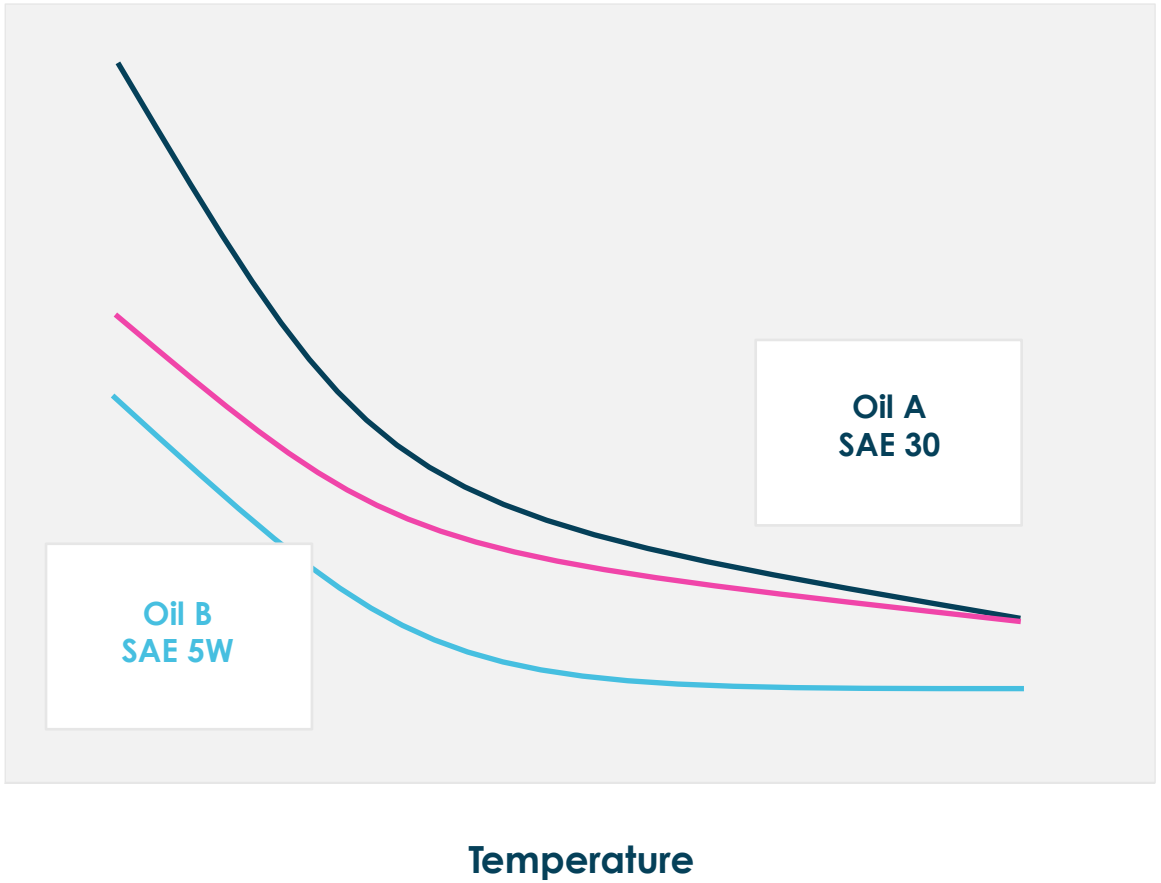


PMAs, temperature sensitive OCPs and HSDs



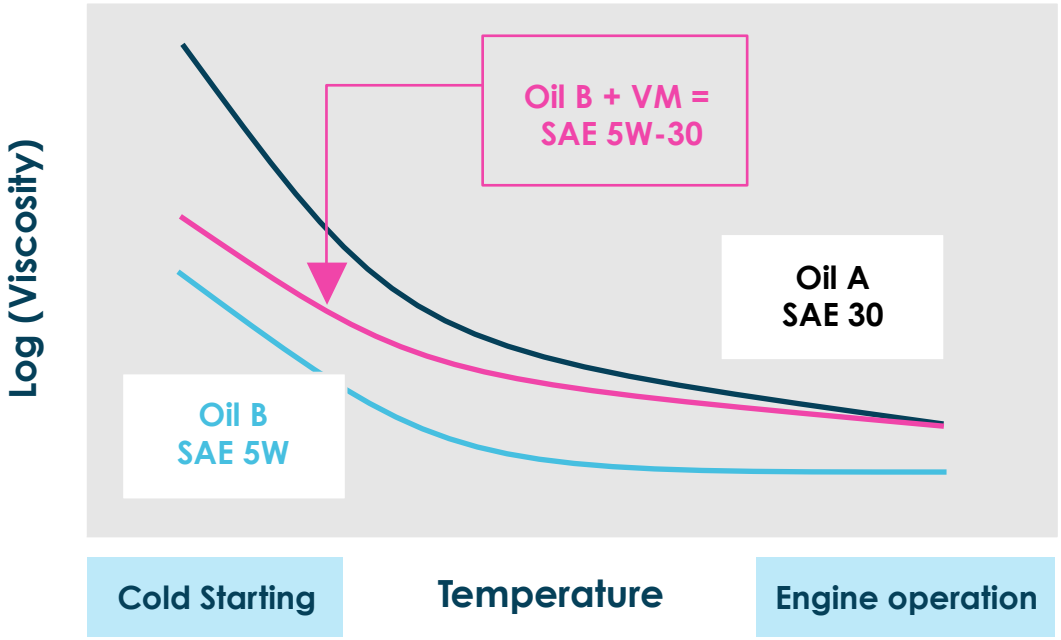
Function of viscosity modifiers

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

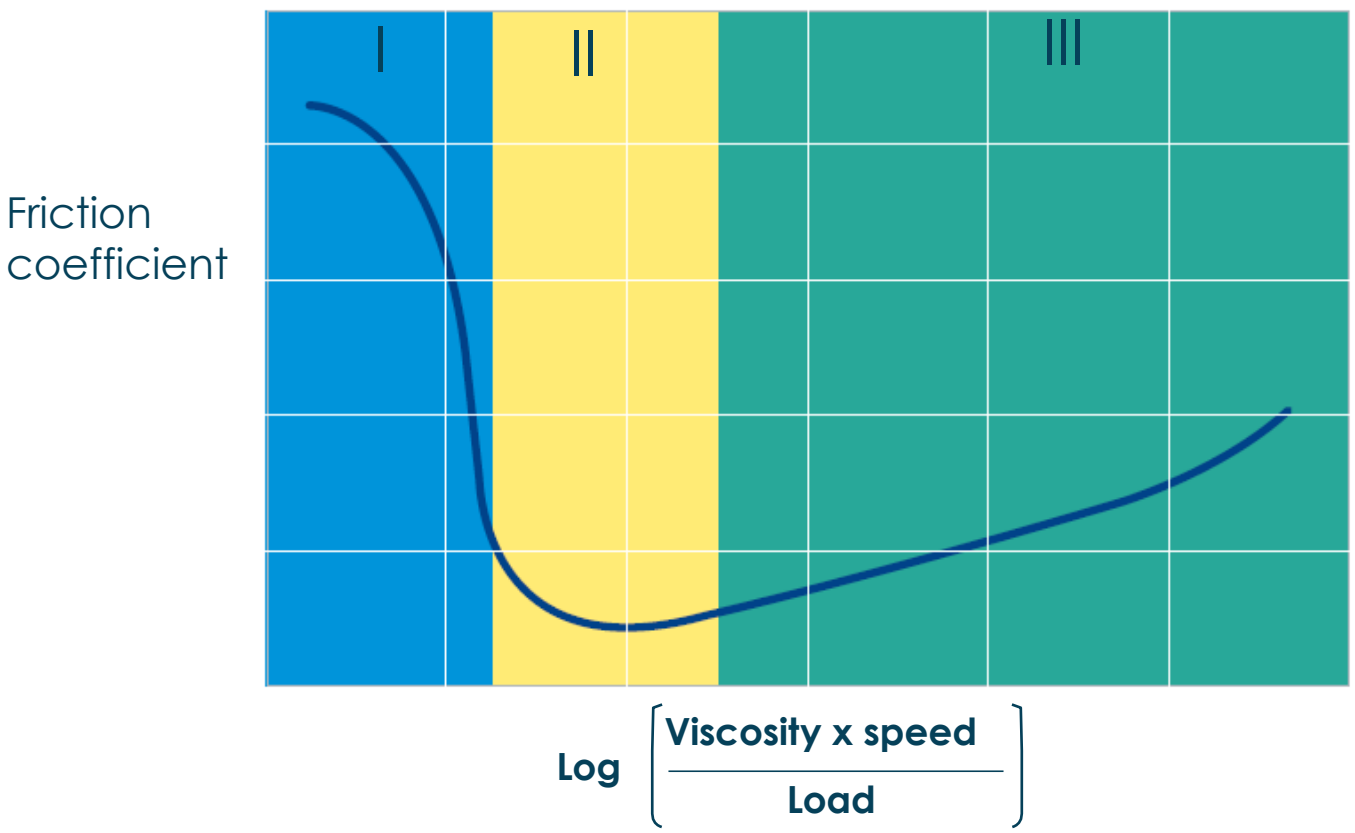
Function of viscosity modifiers



- 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

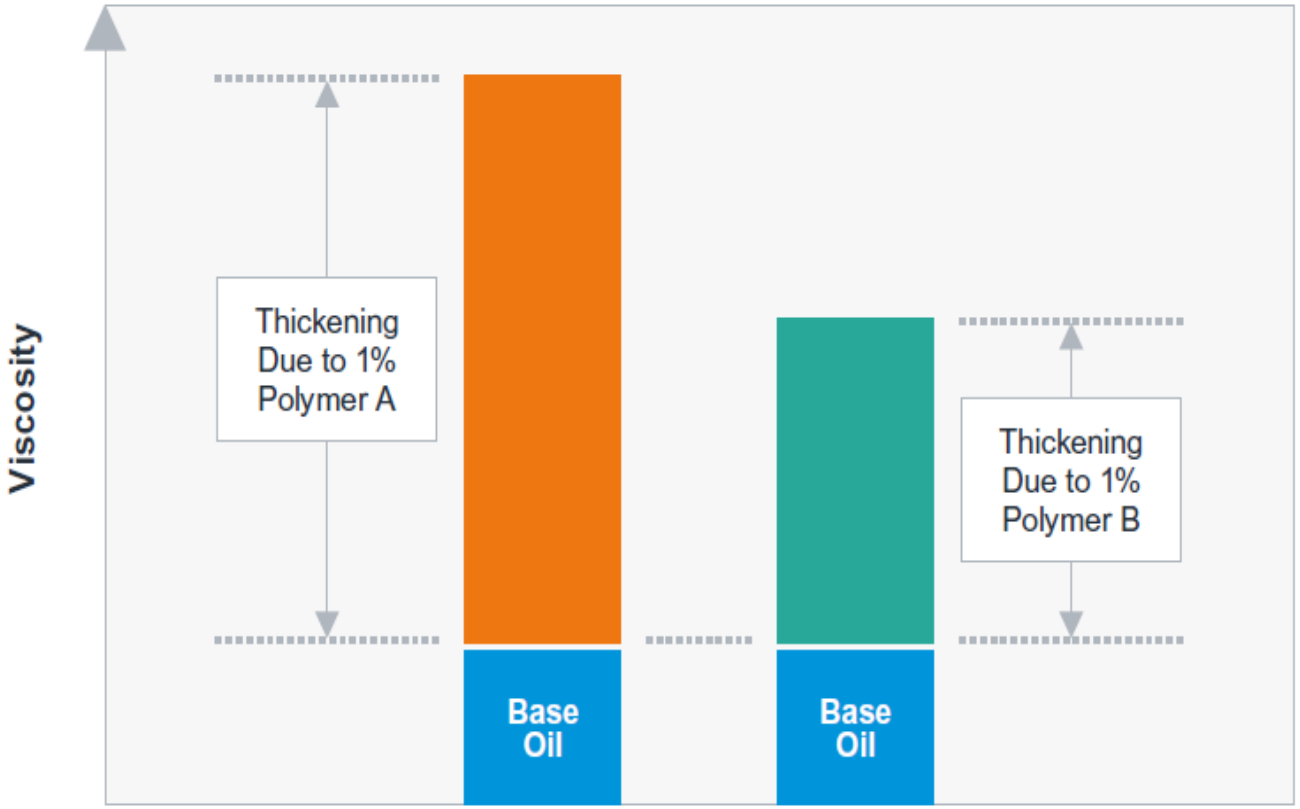
Function of viscosity modifiers - Demo

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

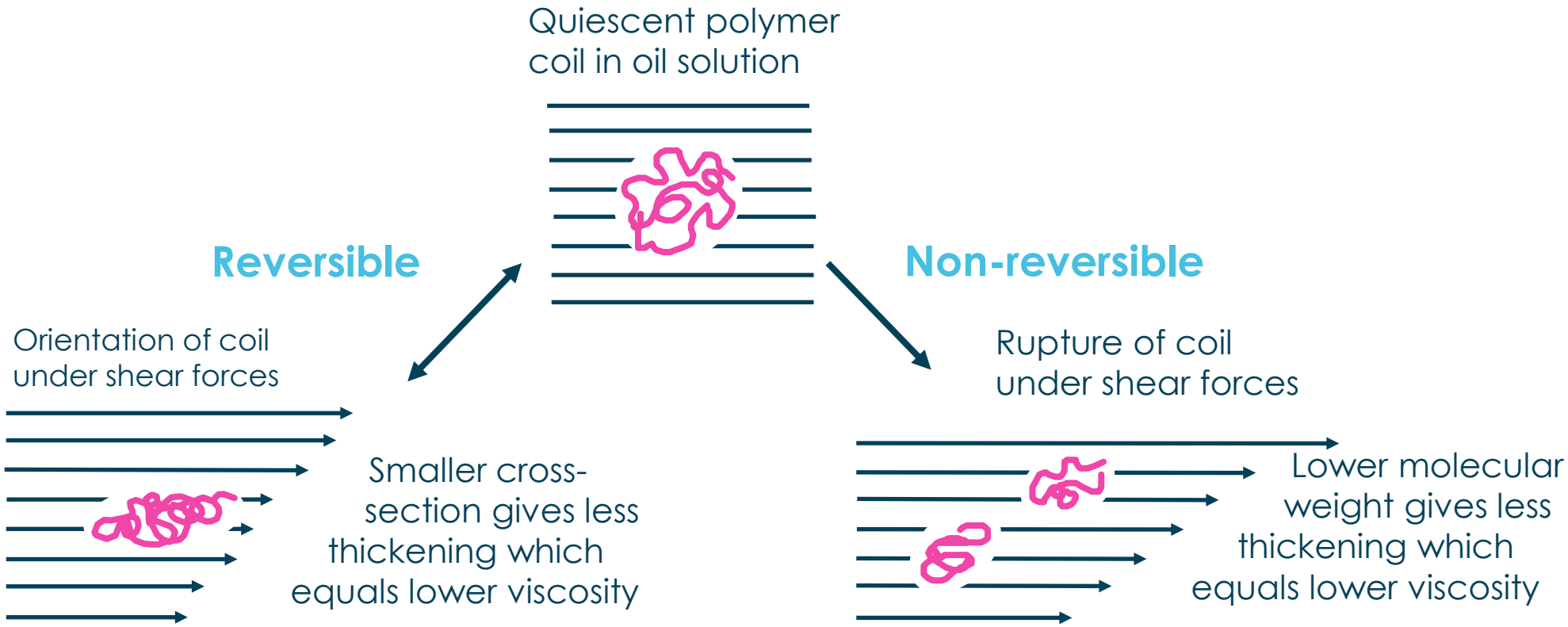
Thickening efficiency



- **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

Shear-thinning:
Temporary & permanent viscosity loss



Temporary Viscosity Loss

Permanent Viscosity Loss:
Shear Stability Index (SSI) measures loss of polymer added viscosity after 30 cycle KO test.

Shear stability index (SSI) (permanent viscosity loss)

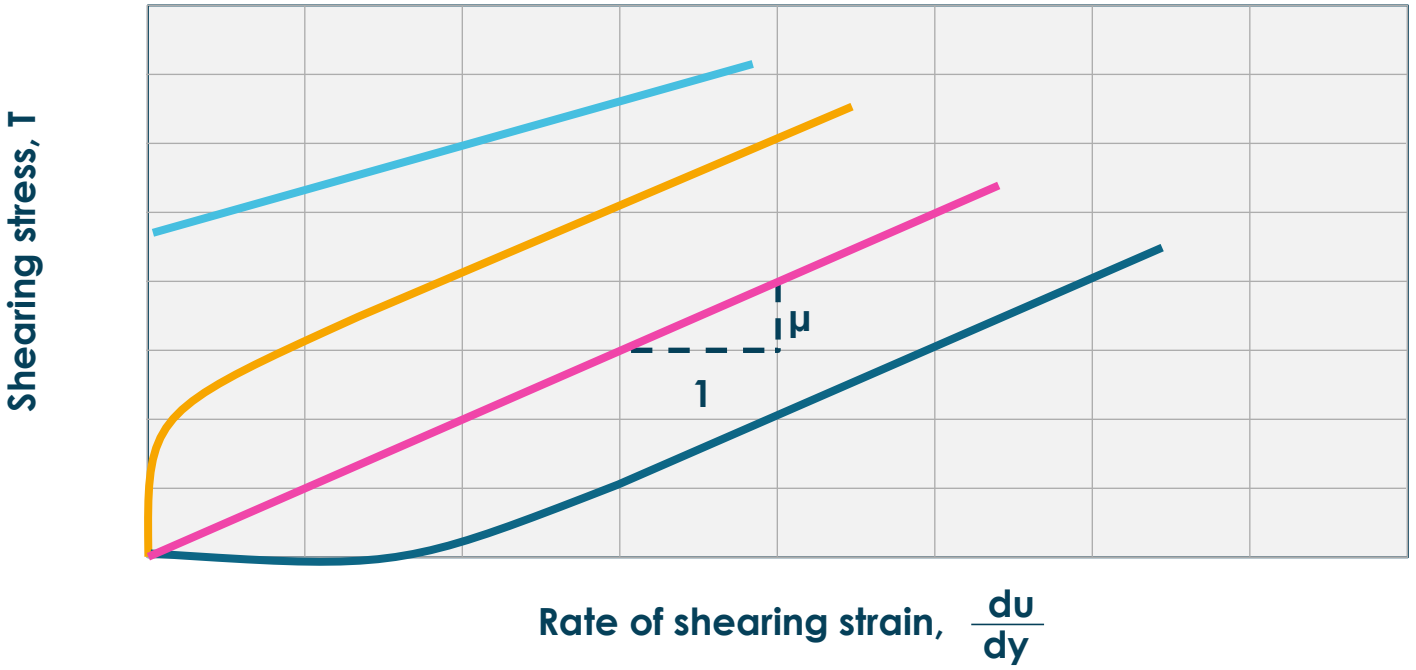
- **Shear Stability Index (SSI)** measures loss of polymer added kinematic viscosity after 30 cycles in Kurt Orbahn

- 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

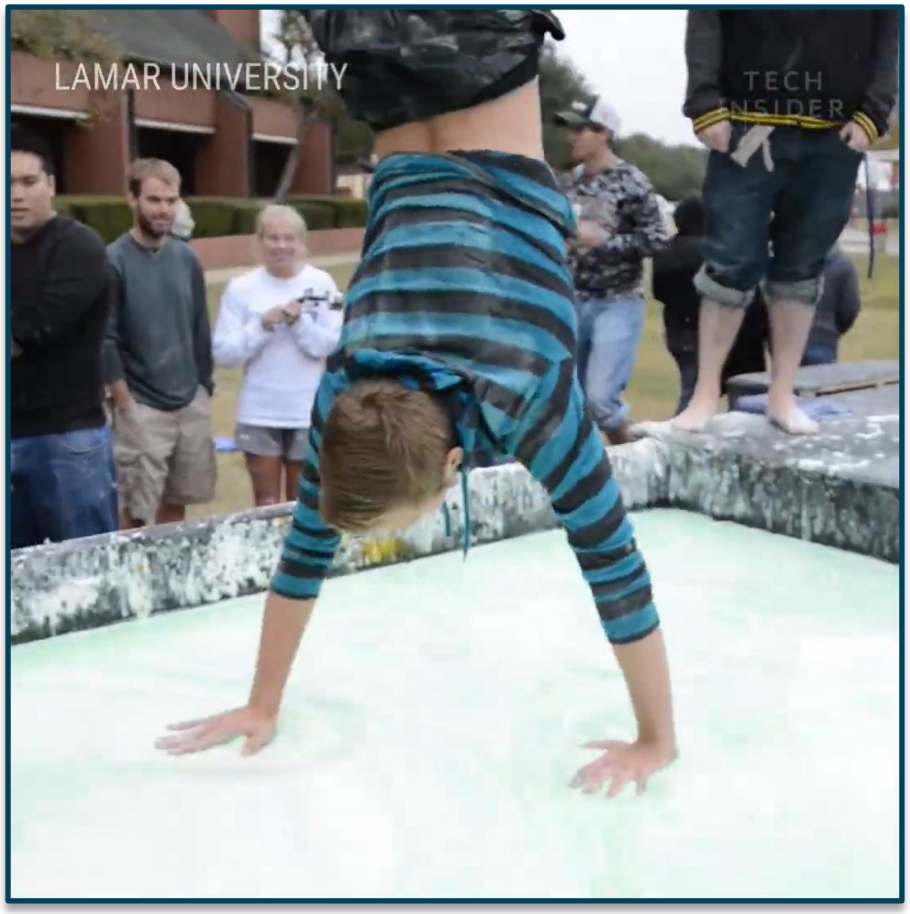
- **SSI depends on** polymer chemistry, molecular geometry and molecular weight
  Higher MW = less shear stable VM

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

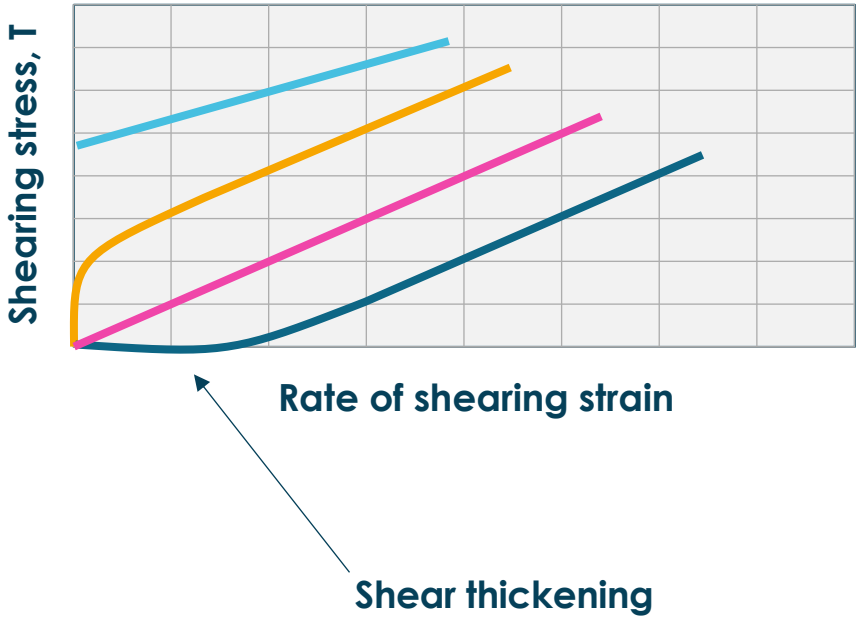


- **Newton's Law of Viscosity:**
  viscosity = shear stress / shear rate
- Newtonian Fluids = viscosity is a constant;
  does not change with shear stress or shear rate
- Fluids that do not obey this are called
  Non-Newtonian
- The most common type is **Shear-Thinning:**
  - Viscosity decreases with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

Shear thickening fluid - Dilatant

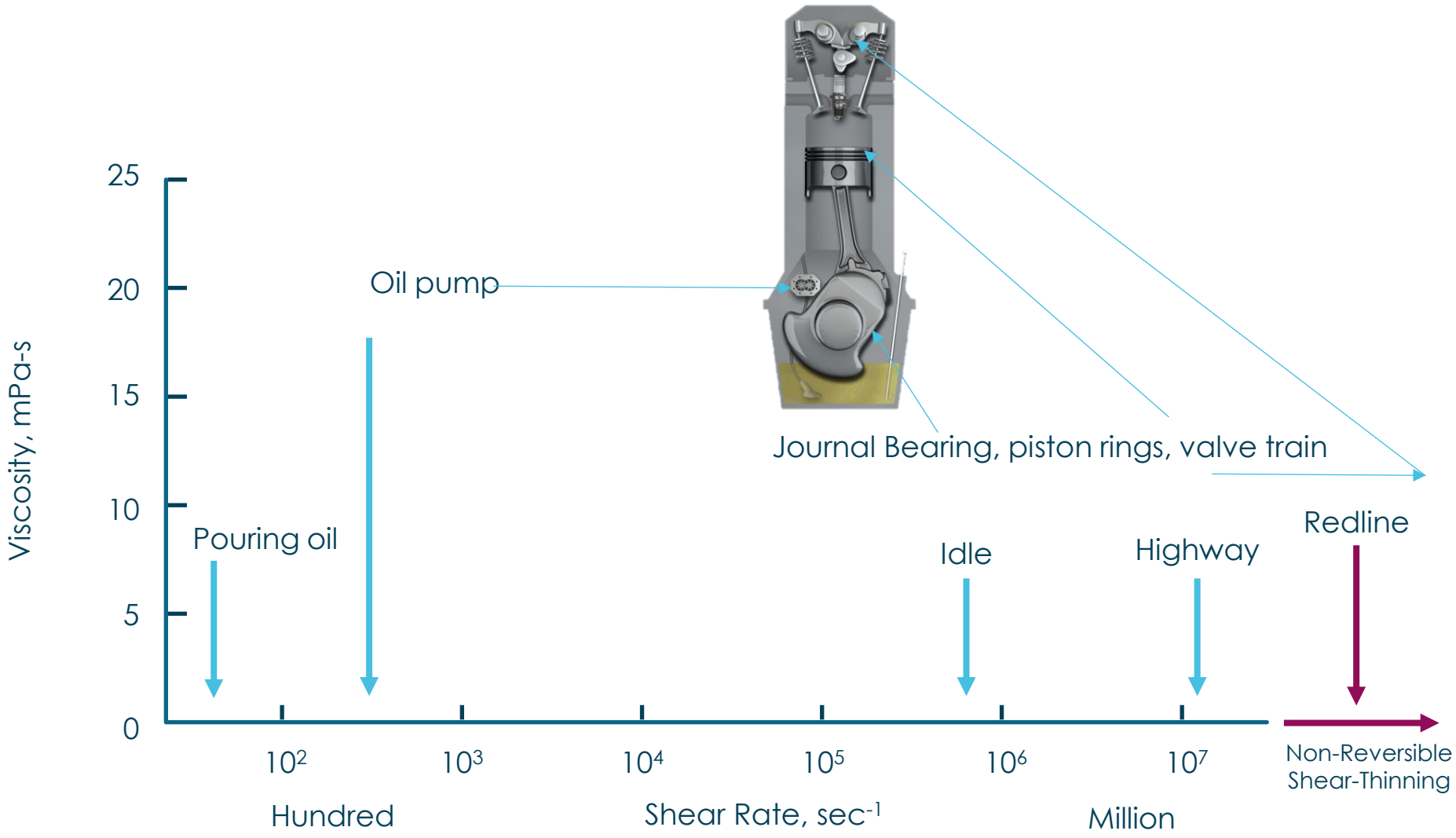


INSIDER Tech https://www.youtube.com/watch?v=q-DZ0f0_NCA

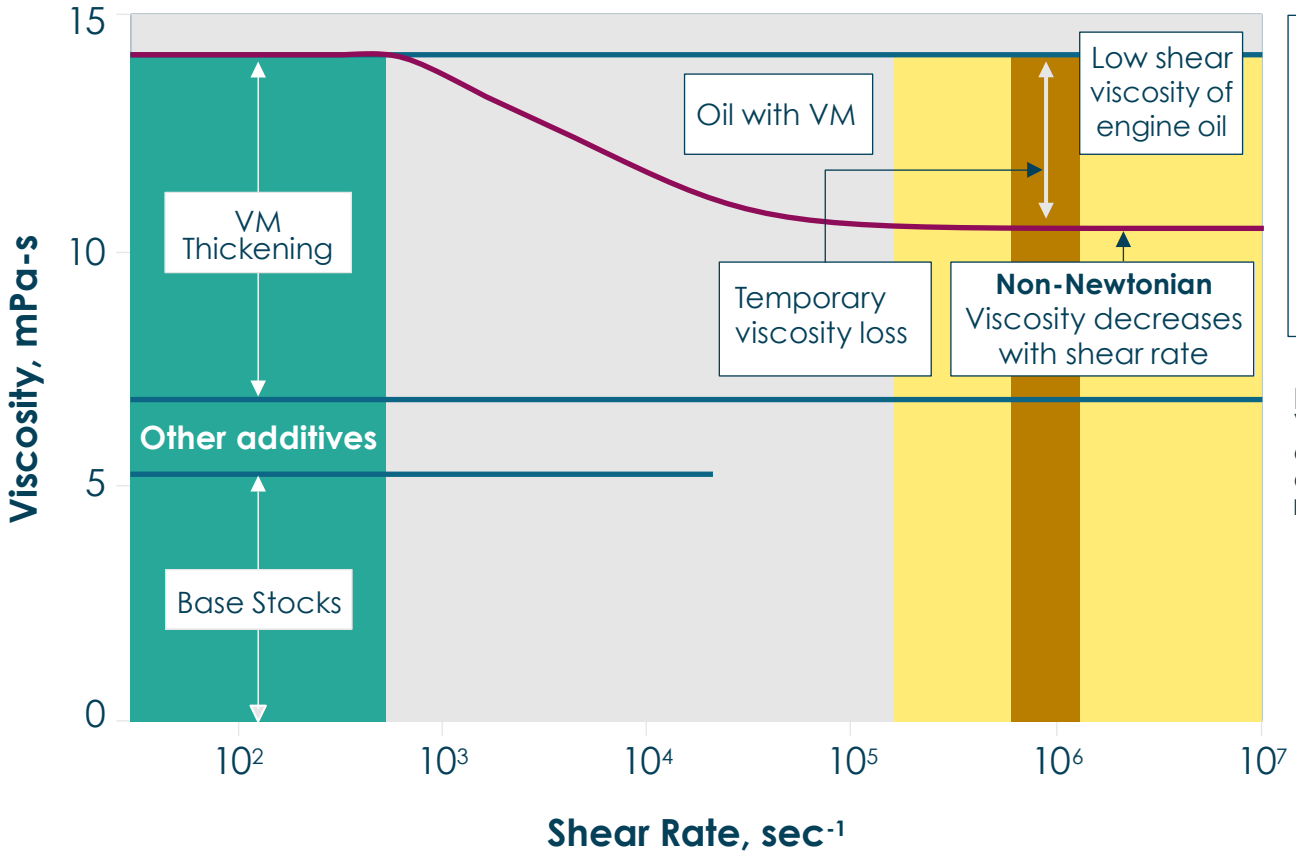


Cornstarch + water suspension = Oobleck

Typical shear rates



Shear rate and shear-thinning

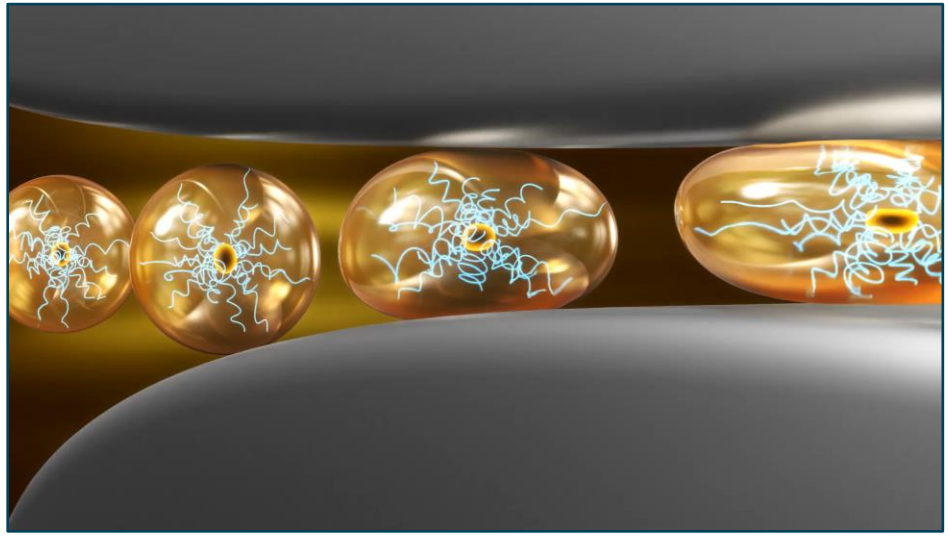


Kinematic Viscosity Shear Rate

Ring Zone, Bearings, Valve Train Shear Rate

High Temperature High Shear (HTHS) Shear Rate

Newtonian
Viscosity is constant at all shear rates



Viscosity modifier types

Common types:

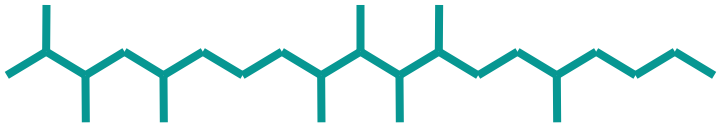
- **Ethylene-Propylene Co-polymer (OCP)**
  - Semi-crystalline
  - Amorphous
- **Hydrogenated Styrene-diene Co-polymer (HSD)**
- **Polymethacrylate (PMA)**

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

Viscosity modifier chemistry

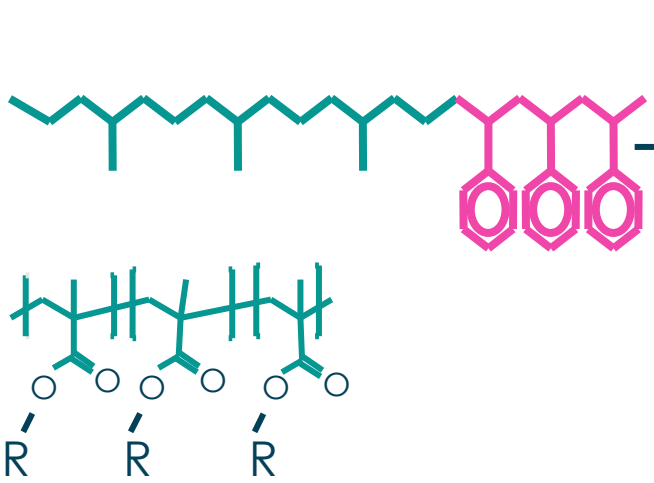
Ethylene-Propylene Co-polymer (OCP)

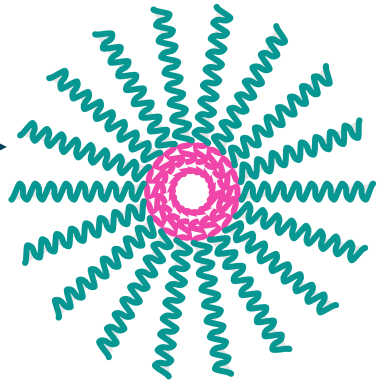


Can be semi-crystalline or amorphous depending on structural details

Hydrogenated Styrene - Diene Co-polymer : Linear Polymer

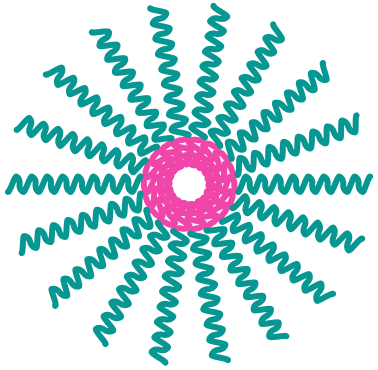
Polymethacrylate: (PMA)





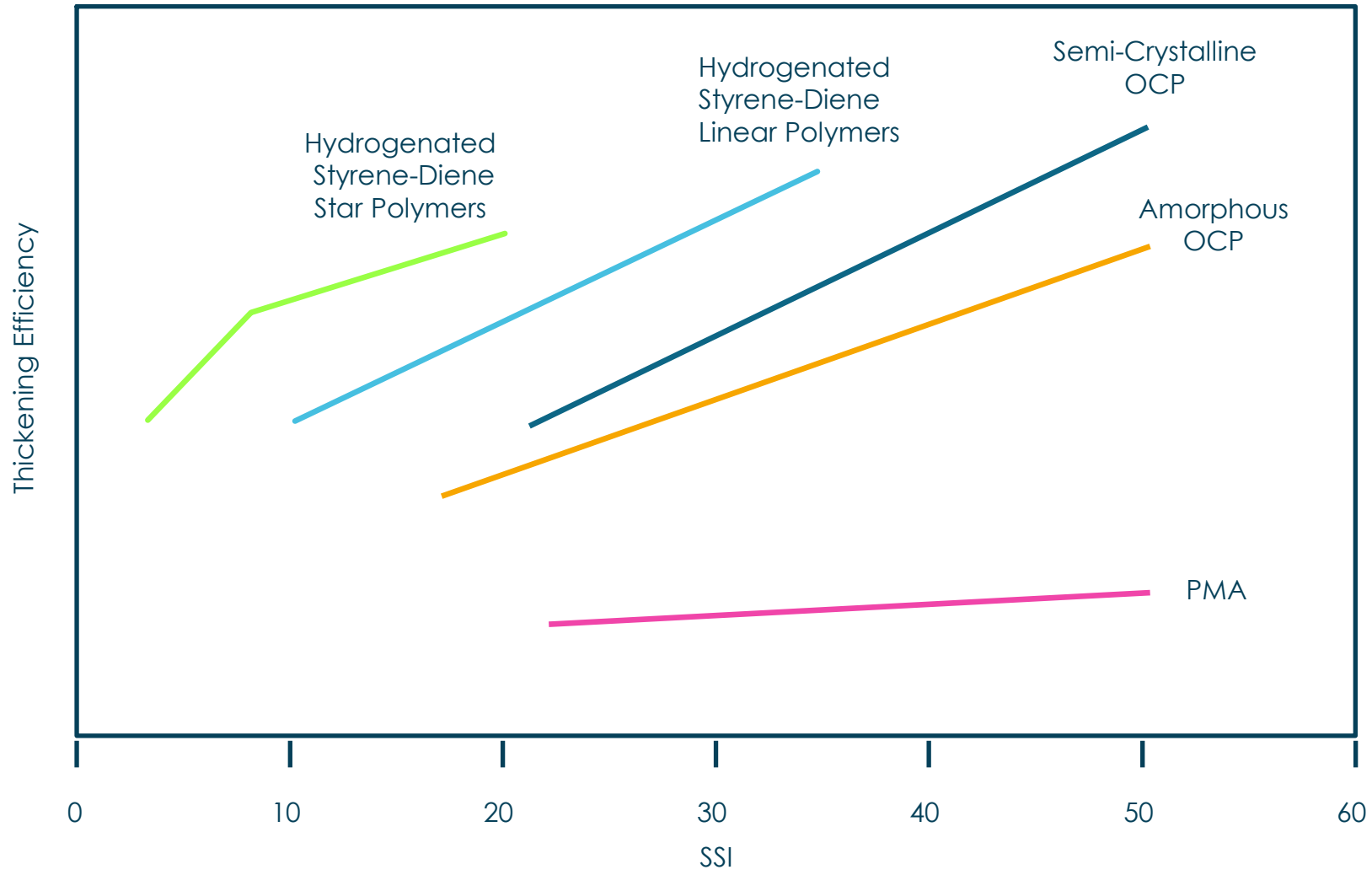
Loose physical association due to polarity differences

Hydrogenated Styrene-Diene: Star Polymer



Chemically bonded together

Performance comparison TE vs. SSI



Used oil properties

Flowability

Infineum SV260 Star retains excellent flowability, even after extensive use in the field

Infineum SV260 oil

Fresh Aged

OCP oil

Fresh Aged

3. Pour point depressants

Pour point depressants

Pour Point Depressants:

Commonly referred to as **PPDs**

Also know as Lube Oil Flow Improvers (**LOFIs**)

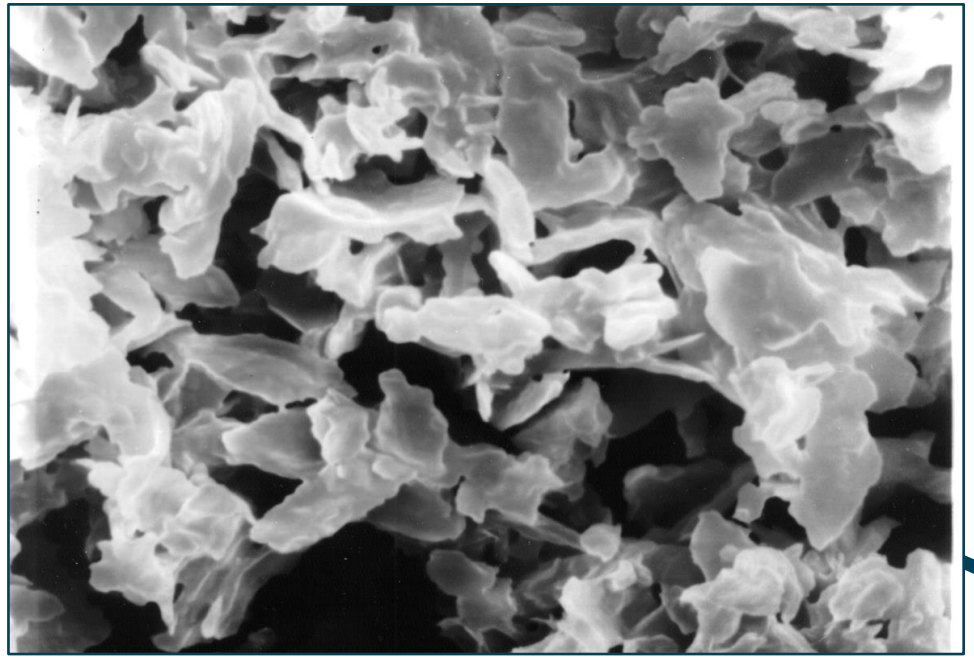
Break up regularity of wax crystals:

- 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**)

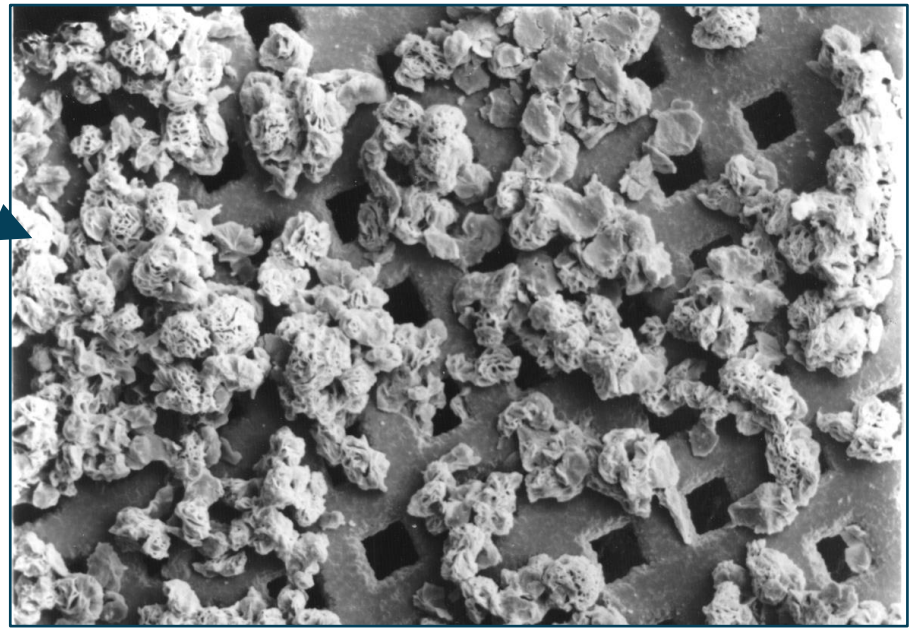
Wax crystal modification by lofi



50 micron

+ LOFI

- 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



5 micron

4. SAE viscosity grades

SAE J300 engine oil viscosity grades (issued Aug 2024)

SAE Grade	CCS mPa-s, Min	CCS mPa-s, Max	MRV mPa-s, Max w/No Yield Stress	Kinematic Viscosity at 100 °C mm²/s		HTHS @ 10^6 Sec^{-1} at 150 C mPa-s, Min
				Min	Max	
0W		6200 at -35°C	60 000 at -40°C	3.8	–	–
5W	6201 at -35°C	6600 at -30°C	60 000 at -35°C	3.8	–	–
10W	6601 at -30°C	7000 at -25°C	60 000 at -30°C	4.1	–	–
15W	7001 at -25°C	7000 at -20°C	60 000 at -25°C	5.6	–	–
20W	7001 at -20°C	9500 at -15°C	60 000 at -20°C	5.6	–	–
25W	9501 at -15°C	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

new

But New GF-7 Limits 40K

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

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

SAE viscosity grades

'Summer' Grade	0W	5W	10W	15W	20W	25W
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					

'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

5. Summary

Summary

1

Viscosity is a measure of a fluid's resistance to flow

It depends strongly on temperature

And it can depend on shear rate

2

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

3

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

Questions?

Thank you

Formulating tomorrow together

Permissions