Engine Friction and Lubrication

2103471 Internal Combustion Engine

Friction

- Friction refers to the forces acting between mechanical components due to their relative motion and to forces on and by fluids when they move through the engine

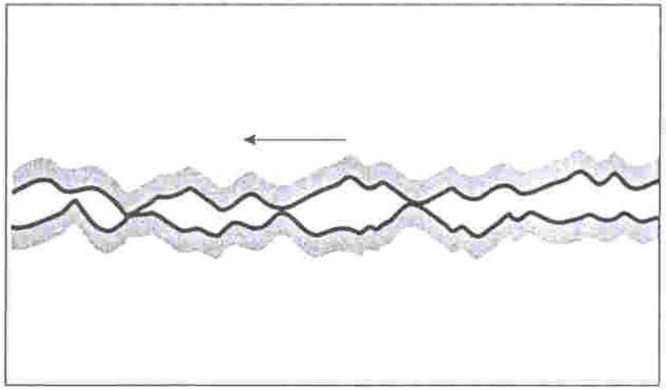
- A percentage of power generated within the engine cylinders are lost to friction, that cause some reduction in the resulting brake power obtained off the crankshaft.

- Engine’s accessories that cause some reduction in crankshaft power are also classified as part of engine friction load.

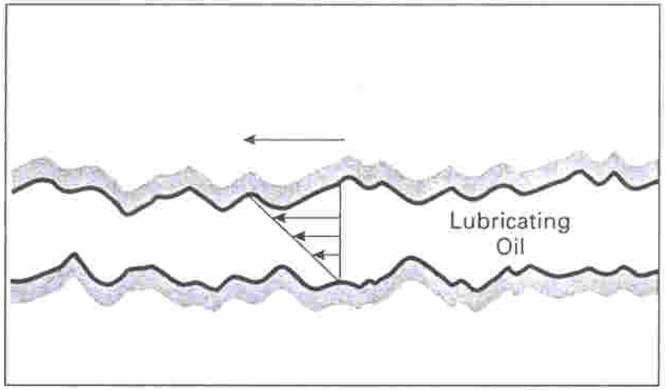
Mechanical Friction and Lubrication

- When two solid surfaces are in contact, they will touch each other at the roughness high spots of the surfaces.
- Points of contact will become hot, sometimes to the point of trying to weld together.
- To reduce resistance of surface-to-surface motion, lubricating oil is added to the space between the surfaces.
- Lubricating oil holds the surface apart and one surface hydrodynamically floats on the others surface.
- The resistance to relative motion is the shearing of fluid layers between the surfaces, which is less than that of dry surface motion.

Mechanical Friction and Lubrication



Dry or non lubricating surface showing friction caused by high spots



lubricating surface showing reduction of friction by hydraulic floating

Characteristics of Lubricating Fluid

Three important characteristics of a lubricating fluid:

- It must adhere to solid surface.
- It must resist being squeezed out from between the surfaces, even under the extreme forces.
- It should not require excessive force to shear adjacent liquid layers.

Engine Friction

- Friction can be classified as a loss using power terms:

$$\dot{W}_f = \left(\dot{W}_i\right)_{net} - \dot{W}_b$$

Where: $$\left(\dot{W}_i\right)_{net} = \left(\dot{W}_i\right)_{gross} - \left(\dot{W}_i\right)_{pump}$$

- Friction can be classified using specific work terms:

$$\dot{w}_f = \left(\dot{w}_i\right)_{net} - \dot{w}_b$$

$$\eta_m = \dot{W}_b / \dot{W}_i = w_b / w_i$$

- Typical methods of classifying and comparing friction and engine losses is in terms of **Mean effective pressure**.

Frictional Work: $$fmep = W_f / V_d$$

Frictional Power: $$fmep = \dot{W}_f / \left[V_d\left(N / n\right)\right]$$

$$fmep = imep - bmep$$

Engine Friction

- Friction mep can be related to engine speed by the empirical equation:

$$fmep = A + BN + CN^2$$

Where N = engine speed

A, B and C = constant

(A is sometimes called boundary friction)

- The constants A, B and C must be determined for the operating conditions of a given engine.

Engine Friction

- Friction mep can also be related to average piston speed by the empirical equation:

$$fmep = A' + B'\overline{U}_p + C'\overline{U}_p^2$$

Where $\bar{U}_p$ = average piston speed

A', B' and C' = constant

- The constants for two equations are related as

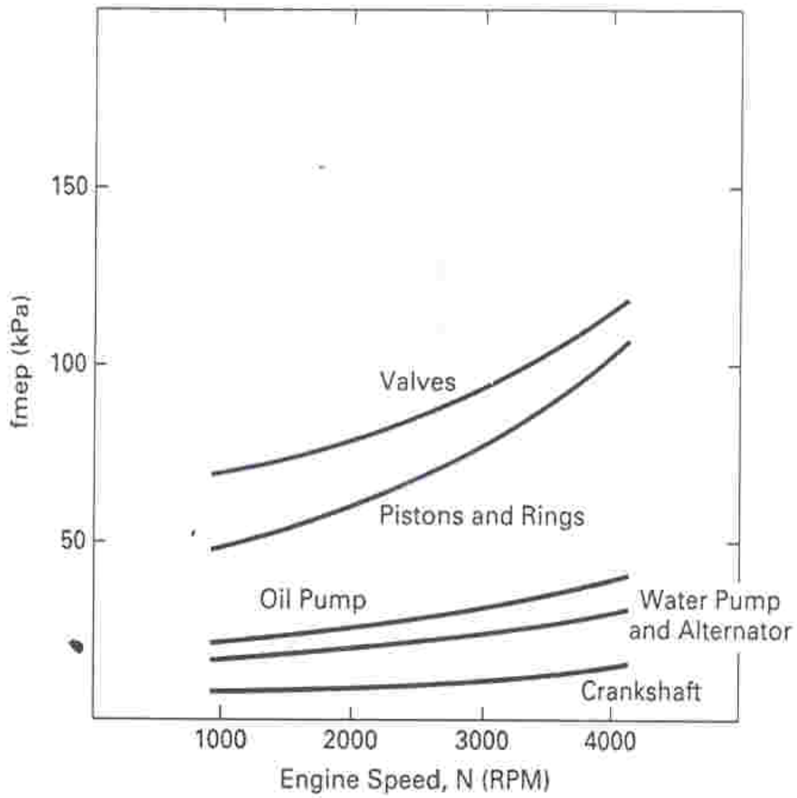
A' = A

B' = B/2S

C' = C/4S^2

Engine Friction

- The components that contribute a major part of total friction are the pistons and piston rings as shown in the figure below



- Percent of friction contributed by various engine components

Engine Friction

The magnitude of the friction forces are classified in two groups as:

- Intake, compression and exhaust stroke – are about the same.
- Expansion stroke – is much higher due to the pressure and forces that occur at that time.

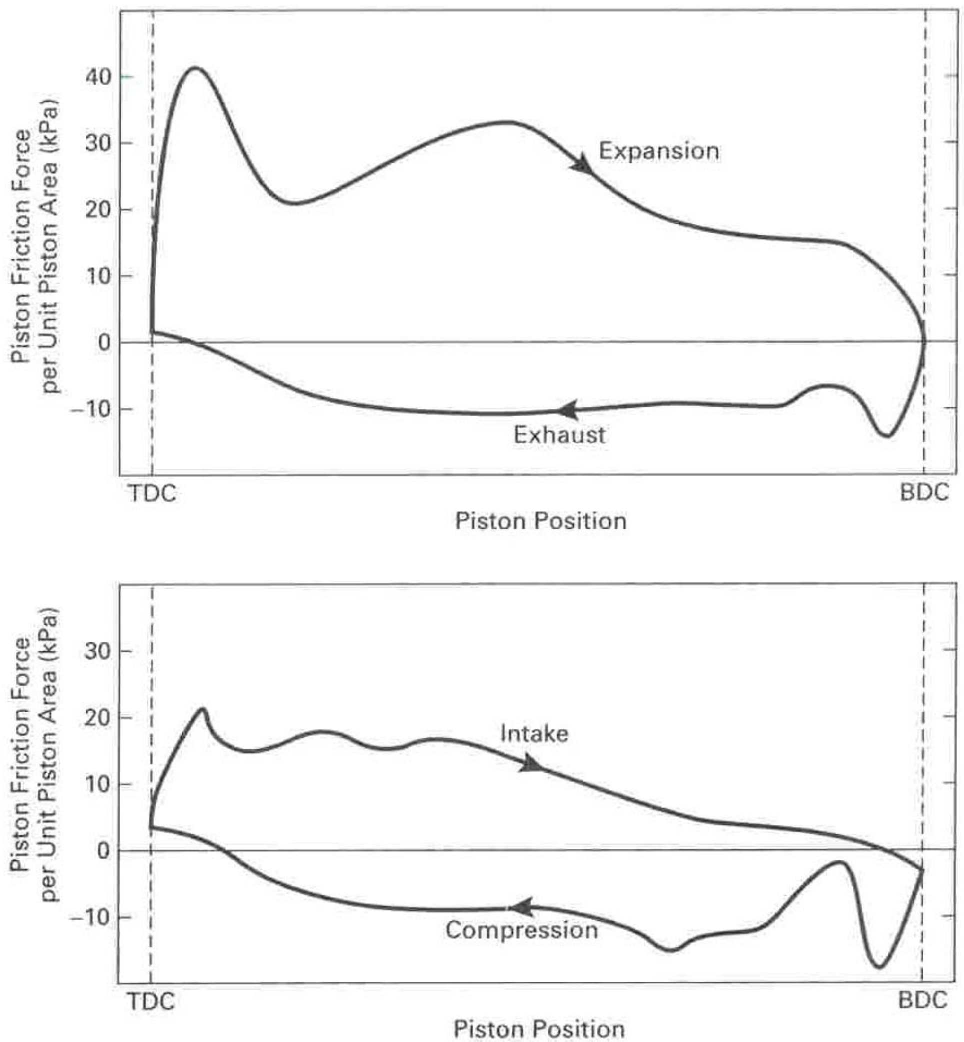
Engine Friction

The contribution of the friction forces are classified as:

- Piston assemblies – contribute about half of the total friction and can be as much as 75% at light load.
  - Piston rings – contribute about 20% of the total friction.
- Valve train – contributes about 25% of the total friction.
- Crankshaft bearing – contributes about 10% of the total load.
- Accessories – contribute about 15% of the total load.

Engine Friction

Engine friction forces during each part of the engine cycle



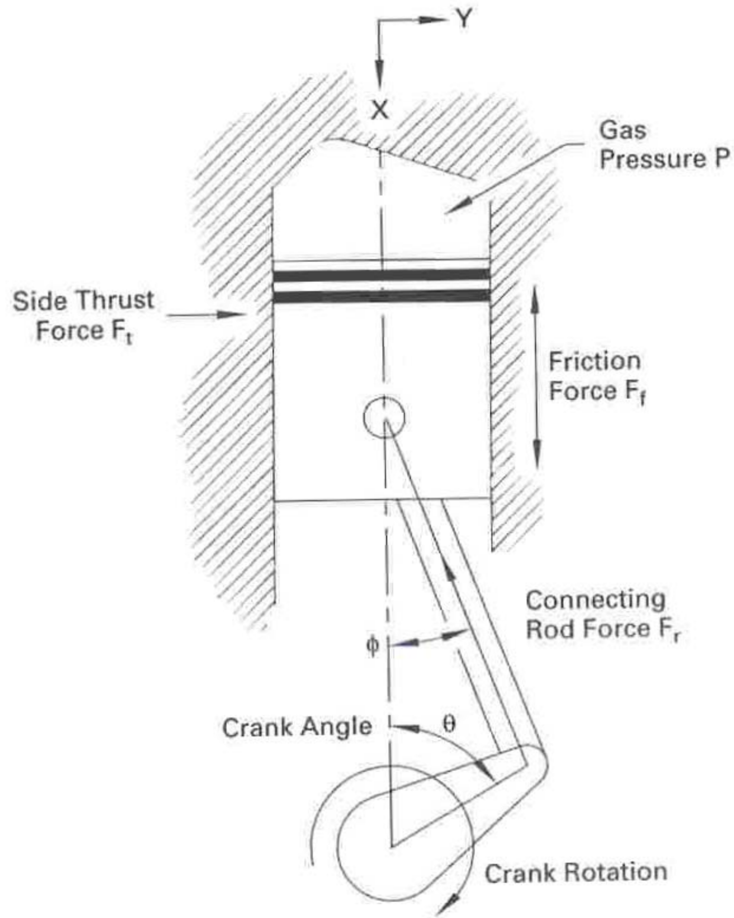
How To Reduce Engine Friction

To reduce engine friction:

- Using piston with
  - less mass – lowers the piston inertia and reduce acceleration.
  - and shorter skirt.
    - Shorter piston skirts reduce rubbing friction because of the smaller surface contact area.
    - Shorter skirts require closer tolerance between the piston and cylinder wall to keep piston from cocking in the cylinder.
- Using fewer and thinner piston rings but require closer tolerances.
- Using offset wrist pin from the center towards the minor thrust side of the piston. To reduce the side thrust force and resulting wear on the major thrust side.
- Using the shorter stroke. This, for a given displacement requires a larger bore which results in
  - greater heat losses due to larger cylinder surface area,
  - Greater knock tendency due to longer flame travelling distance.

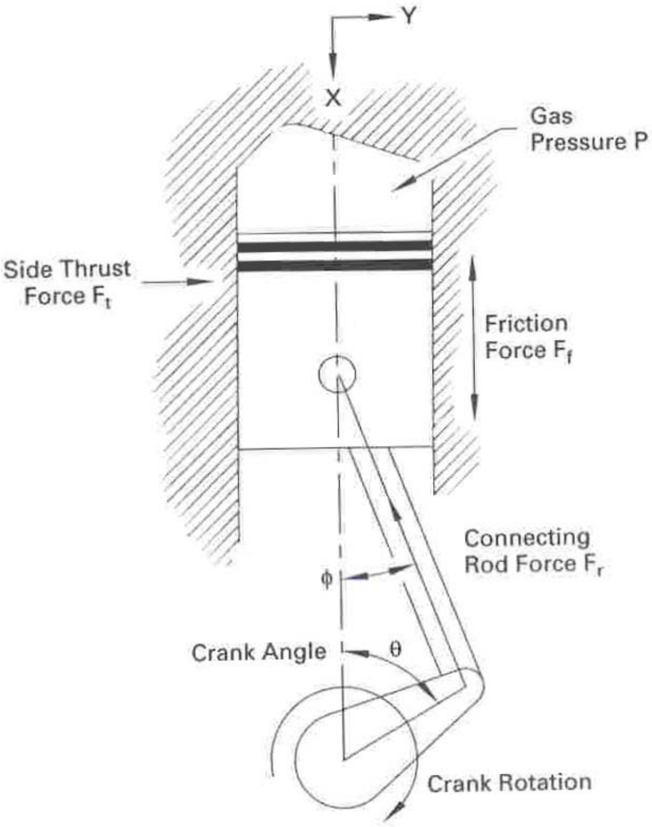
Forces on piston

- Force that act on a piston are shown in figure below.



Forces on piston

- A force balance in the X direction gives.



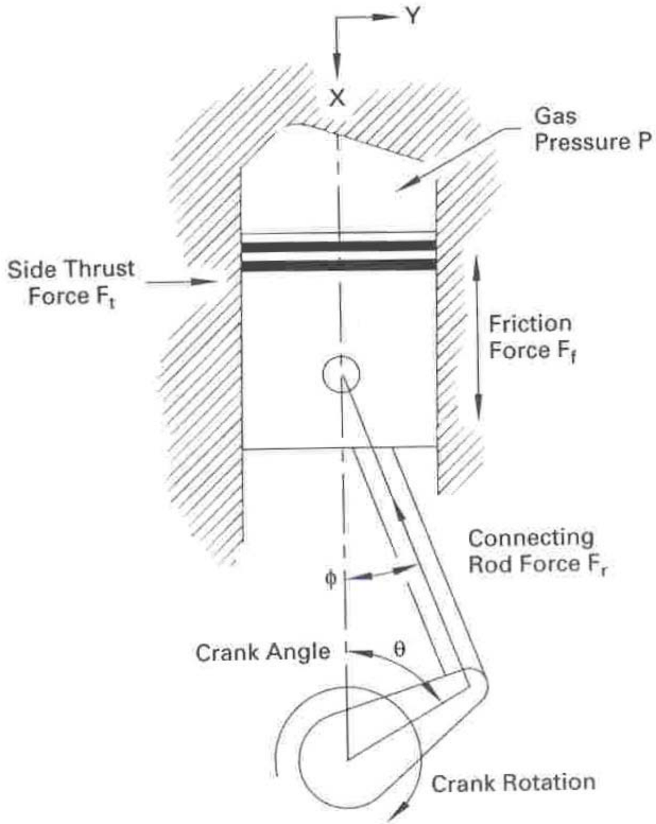
$$\sum F_x = m\left(\frac{dU_p}{dt}\right) = -F_r\cos\phi + P\left(\frac{\pi}{4}\right)B^2 \pm F_f$$

F_f is - when $0^\circ \langle \theta \langle 180^\circ$

\+ when $180^\circ \langle \theta \langle 360^\circ$

Forces on piston

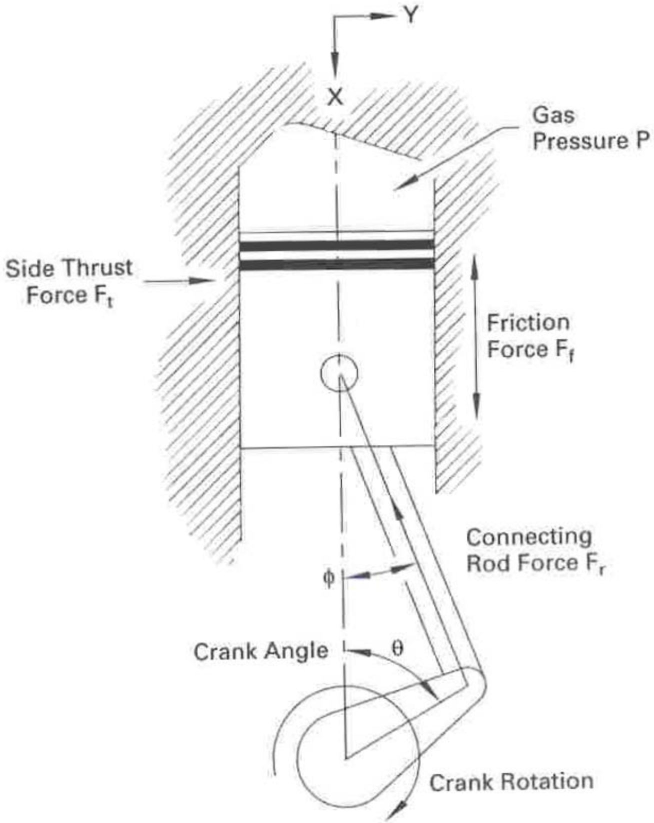
- A force balance in the Y direction gives.



$$\sum F_y = 0 = F_r \sin\phi - F_t$$

Forces on piston

- A combined force in X and Y direction gives the side thrust force on the piston as.



$$F_t = \left[-m\left(\frac{dU_p}{dt}\right) + P\left(\frac{\pi}{4}\right)B^2 \pm F_f \right]\tan\phi$$

F_t is not a constant force but changes with

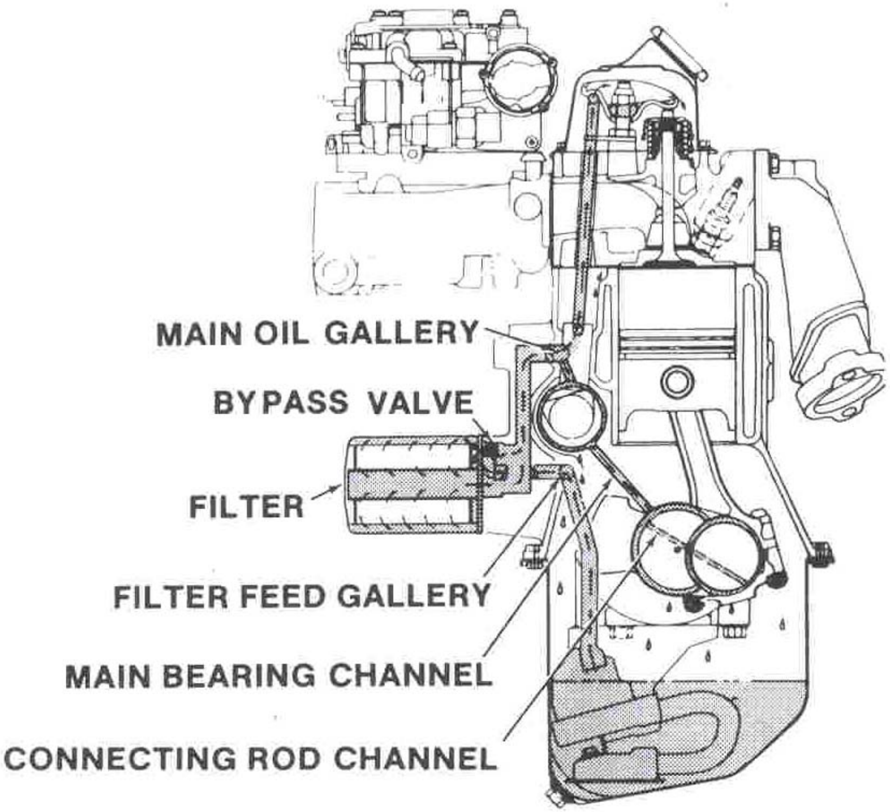
- piston position (Crank angle),
- piston acceleration,
- in-cylinder pressure,
- friction force.

All of these vary during the engine cycle.

Engine Lubrication System

Three basic types of oil distribution systems used in engine are:

- Splash
- Pressurized
- Combination of splash and pressurized.



Lubricating Oil

The oil used in an engine must serve as

- a lubricant,
- a coolant, and
- a removal impurity.

Lubricating Oil

Required properties for the lubricating oil used in an engine:

- must operate over an extreme temperature range.
- must lubricate properly from the starting temperature to beyond the extreme steady-state temperatures that occur within the engine cylinders.
- must not oxidize on the combustion chamber walls or at other hot spots.
- should adhere to surfaces so that they always lubricate and provide a protective covering against corrosion.
- should have high film strength to assure on metal-to-metal contact even under extreme loads.
- should be non-toxic and non-explosive.

Lubricating Oil

Lubricating oil must satisfied the following needs:

- Lubrication – It must reduce friction and wear within the engine. It improves engine efficiency by reducing friction forces between moving parts.
- Coolant
- Removal of contaminants
- Enhancement of ring seal and reduction of blowby
- Slow corrosion
- Stability over a large temperature range
- Long life span
- Low cost

Lubricating Oil Additives

For maximum performance and life span of the engine, following additives are required:

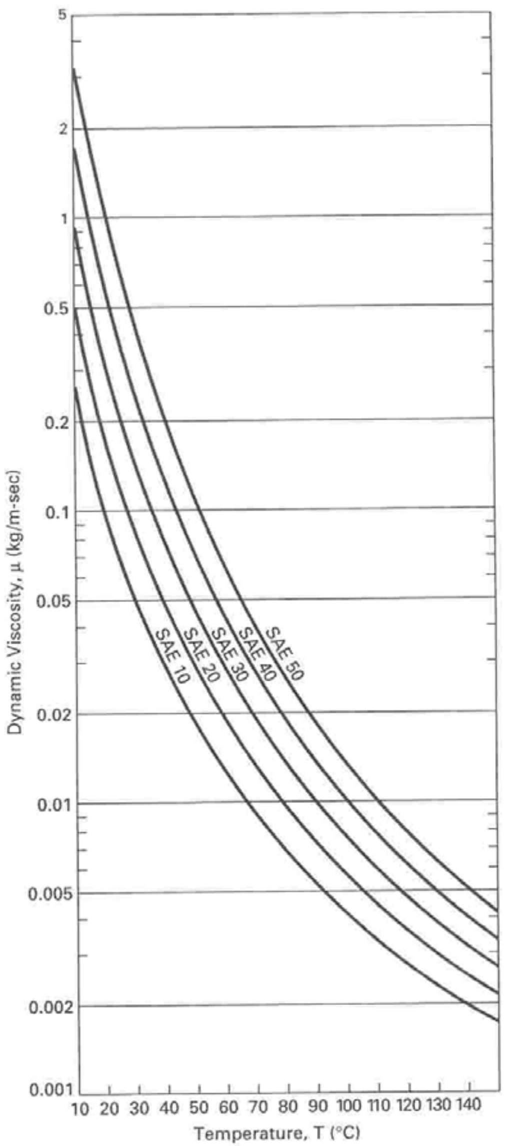
- Antifoam agents
- Oxidation inhibitors
- Pour-point depressant
- Antirust agents
- Detergents
- Antiwear agents
- Friction reducers
- Viscosity index improvers

Lubricating Oil Additives

For maximum performance and life span of the engine, following additives are required:

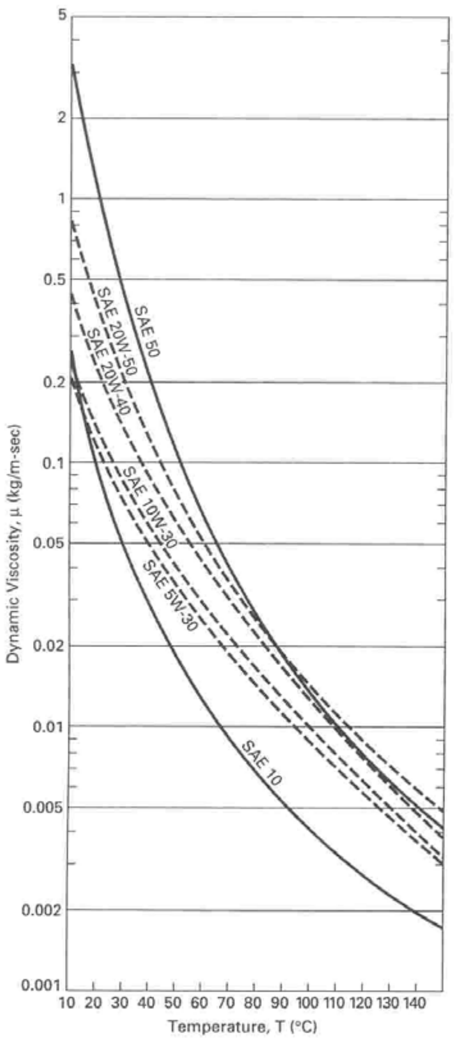
- Antifoam agents
  - These reduce the foaming that would result when the crankshaft and other components rotate at high speed in the crankcase oil sump.
- Oxidation inhibitors
  - Oxygen is trapped in the oil when foaming occurs, and this leads to possible oxidation of engine components.
  - Such additive is zinc dithiophosphate.
- Detergents
  - These are made from organic salts and metallic salts.
  - They keep deposits and impurities in suspension and stop reactions that form varnish and other surface deposits.
  - They help neutralized acid formed from sulfur in the fuel.

Lubricating Oil Viscosity



- Lubricating oil are rated using a viscosity scale established by SAE.
- The higher the viscosity value, the greater the force required to move adjacent surface or pump oil through a passage.
- Common viscosity grades are:
  - SAE 5, – SAE 10,
  - SAE30 – SAE 40,
  - SAE45 – SAE50.

Multigrade Oil



- Multigrade oil was developed so that viscosity would be more constant over the operating temperature range.
- A value such as SAE 10W-30 means that the oil has properties of 10 viscosity when it is cold (W=constant) and 30 viscosity when it hot.
- Some studies show that polymers added to modify viscosity do not lubricate well as the base hydrocarbon oil.
- Common viscosity grades are:
  - SAE 10W-30, – SAE 15W-40,
  - SAE 10W-40, – SAE 15W-50,
  - SAE 10W-50, – SAE 20W-50.