Unit 5: Lubricants

Engineering Chemistry — DI01000071

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Unit 5 covers classification of lubricants, mechanisms of lubrication, essential properties (viscosity, flash/fire point, cloud/pour point, acid value, saponification number, aniline point), and industrial applications.

Unit 5 — Topics and Weightage

Topics at a Glance

#	Topic	Key Concepts
1	Definition and functions	Reduce friction, wear, heat
2	Classification	Liquid, semi-solid, solid
3	Liquid lubricants	Mineral, vegetable, animal, blended
4	Greases	Semi-solid; extreme pressure
5	Solid lubricants	Graphite, MoS_2; high-temp use
6	Mechanisms	Hydrodynamic, boundary, extreme pressure
7	Viscosity and index	Resistance to flow; VI improvers
8	Flash/fire point	Safety; volatile impurities
9	Cloud/pour point	Low-temp performance
10	Acid value, saponification	Quality, degradation
11	Aniline point	Aromatic content indicator

Weightage: $\approx$10% | GTU: 2 $\times$ 7-mark + short answers

Lubricants — Definition and Functions

Definition

A **lubricant** is any substance introduced between two moving surfaces to reduce **friction**, **wear**, and **heat generation**.

Functions of a Lubricant

1	Reduce friction between moving parts
2	Minimize wear and surface damage
3	Carry away heat generated at contact surfaces
4	Prevent corrosion/rust on metal surfaces
5	Act as a seal (prevent entry of dust, moisture)
6	Absorb shocks between machine parts
7	Carry away metal particles and contaminants

Classification of Lubricants

Type	Subtype	Examples
Liquid	Mineral oils	Engine oil, turbine oil, hydraulic oil
	Vegetable oils	Castor oil, olive oil, palm oil
	Animal oils	Lard oil, fish oil, sperm oil
Semi-solid	Greases	Calcium, lithium, sodium grease
Solid	Organic	Graphite, MoS_2, PTFE (Teflon)
	Inorganic	Talc, mica, silica powder

Selection basis: Load, speed, temperature, environment, compatibility with materials.

Liquid Lubricants — Mineral Oils

Mineral Oils

Derived from petroleum refining (lube oil fraction, B.P. $>400^\circ C$). Most widely used lubricants. Contain paraffinic, naphthenic, and aromatic hydrocarbons.

Paraffinic Oils

High viscosity index (VI)
Good oxidation resistance
High pour point (wax content)
Best for engine oils

Naphthenic Oils

Low pour point (less wax)
Lower VI than paraffinic
Good for low-temperature use
Used in refrigeration systems

Greases — Semi-Solid Lubricants

What is Grease?

Grease = Mineral oil + thickener (metallic soap) + additives.
Semi-solid consistency; stays in place without leaking; used where liquid oil cannot be retained.

Type	Thickener	Properties / Uses
Calcium grease	Ca soap	Water resistant; chassis, bearings
Sodium grease	Na soap	Not water resistant; high temp. use
Lithium grease	Li soap	Multi-purpose; water resistant; best overall
Barium grease	Ba soap	EP (extreme pressure) use
Bentonite grease	Clay	No drop point; high-temp

Solid Lubricants

When Are Solid Lubricants Used?

At very high temperatures or high pressures where oils/greases fail; in vacuum (space); where contamination by oil is not permitted (food, textile).

Graphite

Layered hexagonal structure; weak van der Waals forces between layers allow easy shear

Good up to $\sim$500°C in air

Needs adsorbed vapour (poor in vacuum!)

Burns above 650°C

MoS_2 (Molybdenum Disulfide)

Layered hexagonal structure; low friction in vacuum (unlike graphite)

Good up to $\sim$350°C

Excellent for aerospace, high-vacuum applications

Mechanisms of Lubrication

Mechanism	Film Condition	Characteristics
Hydrodynamic (fluid film)	Thick film; surfaces fully separated	Lowest friction; no metal contact; ideal
Elasto-hydrodynamic (EHD)	High-pressure thin film	Gears, rolling bearings; film forms under load
Boundary lubrication	Very thin film; surfaces nearly contact	High load, low speed; additive chemistry critical
Extreme pressure (EP)	Metal-to-metal contact	EP additives (S, P, Cl compounds) react with metal to form low-shear films

Stribeck curve: Shows transition from boundary → mixed → hydrodynamic as speed×viscosity/load increases.

Viscosity — Definition and Significance

Definition

Viscosity = resistance of a fluid to flow. It is the **most important** property of a lubricant.

Dynamic viscosity (η): $\tau = \eta \cdot \dfrac{dv}{dy}$ (Pa·s or poise)

Kinematic viscosity (ν): $\nu = \eta/\rho$ (m^2/s or cSt)

Too low viscosity	Insufficient film; metal contact; wear
Too high viscosity	High internal friction; power loss; poor circulation
Ideal	Lowest viscosity that still maintains full lubrication film

Viscosity Index (VI)

Definition

Viscosity Index (VI): An empirical number indicating how much the viscosity of an oil changes with temperature.

High VI = viscosity changes *less* with temperature = better oil for wide temperature range

VI Scale (Dean and Davis)

Reference oils: Pennsylvania oil (paraffinic) = VI 100 | Gulf Coast oil (naphthenic) = VI 0

$$\mathrm{VI} = \frac{L - U}{L - H} \times 100$$

where L = viscosity of VI-0 oil, H = viscosity of VI-100 oil, U = viscosity of test oil (all at 40°C, referenced to 100°C viscosity)

Flash Point and Fire Point

Flash Point

Lowest temperature at which lubricant vapour **momentarily ignites** when a flame is applied (vapours flash but don't sustain burning).

Significance:
– Safe operating temperature
– Detect volatile impurities
– Higher FP $=$ safer use

Fire Point

Temperature at which vapours **sustain continuous burning** for at least 5 seconds.

Fire point $>$ Flash point (always)

Typical:
Engine oil FP $\approx 200^\circ$C
Fire point $\approx 220^\circ$C

Test methods: Pensky-Martens (closed cup) and Cleveland (open cup) apparatus.

Cloud Point and Pour Point

Cloud Point

Temperature at which a lubricating oil first becomes **cloudy or hazy** when cooled, due to precipitation of wax crystals.

Significance: Indicates start of wax separation; wax may clog filters/pipes

Pour Point

Lowest temperature at which an oil **still flows** (can be poured) when cooled under standard conditions.

Pour point = last temperature at which flow observed + 3°C

Pour point > **Cloud point** always

Low pour point required for lubricants used in cold climates (arctic gear oils), refrigeration, aviation.

Acid Value (Acid Number)

Definition

Acid value (AV): Number of milligrams of KOH required to neutralize the free acids present in **1 gram** of lubricating oil.

Units: mg KOH / g oil

Significance

Fresh oil	Low AV (few free acids)
Degraded/oxidized oil	High AV (acids formed by oxidation, hydrolysis)
High AV	Corrosive to metals; oil must be changed

AV is a measure of oil deterioration in service.

Saponification Number (Value)

Definition

Saponification number (SN): Number of milligrams of KOH required to saponify (hydrolyze) the esters present in **1 gram** of oil.

Units: mg KOH / g oil

Significance

Mineral oil	Low SN (≈0; no esters)
Vegetable oil	High SN (many ester linkages)
Animal fat	High SN
Blended oil	Intermediate SN

SN indicates the proportion of fatty oils (esters) in the lubricant.

Aniline Point

Definition

Aniline point: Lowest temperature at which equal volumes of aniline and lubricating oil are **completely miscible** (form a single phase).

Units: $^\circ$C

Significance

Low aniline point	High aromatic content (dissolves aniline easily)
High aniline point	High paraffinic content (less aromatic)

Low aniline point: Oil will swell rubber seals/gaskets (not suitable where rubber is present)
High aniline point: Safe for rubber seals; paraffinic oil

Oiliness (Lubricity)

Definition

Oiliness (lubricity): The ability of a lubricant to **adhere to metal surfaces** and form a thin, tenacious boundary film even under high load and low speed (boundary lubrication regime).

High oiliness	Fatty acids, esters, animal oils
Low oiliness	Pure mineral oils
Improvement	Add oiliness agents (fatty acids, sulfur compounds, EP additives)

Oiliness **cannot** be measured by viscosity — it depends on film-forming ability and molecular polarity.

Emulsification and Demulsibility

Emulsification

Formation of a stable oil-water mixture (emulsion).

Desirable when: Cutting fluids, soluble oils (cooling + lubrication in machining).

Emulsifying agents (soaps) stabilize the emulsion.

Demulsibility

Ability of oil to **separate from water** quickly after mixing (high demulsibility = good).

Desirable when: Turbine oils, hydraulic oils — water contamination should be removed quickly.

High water retention $\Rightarrow$ corrosion, foaming, poor lubrication.

Lubricant Additives

Additive	Example	Function
Antioxidants	Phenols, ZnDTP	Prevent oil oxidation and gum formation
Antiwear (AW)	ZnDTP	Reduce wear under moderate loads
Extreme pressure (EP)	S, P, Cl compounds	Form low-shear films under very high load
Viscosity index improvers	Polymethacrylates	Reduce viscosity-temperature sensitivity
Pour point depressants	Alkyl naphthalenes	Prevent wax crystal growth at low temp
Detergents/dispersan	Sulfonates, PIBSA	Keep engine clean; disperse soot/sludge
Corrosion inhibitors	Benzotriazole	Protect metal surfaces
Antifoam agents	Silicones	Prevent foam formation

Refining of Mineral Lubricating Oils

Steps in Lube Oil Refining

Lube oil fraction from vacuum distillation is further refined to remove unwanted components:

#	Process	Purpose
1	Deasphalting	Remove asphaltenes (propane extraction)
2	Solvent extraction	Remove aromatics; improve VI (NMP or furfural)
3	Dewaxing	Remove wax; lower pour point (MEK-toluene)
4	Hydrotreating	Remove S, N; oxidation stability; brighten colour
5	Blending	Add base oil + additives for final grade

SAE Viscosity Grades for Engine Oils

SAE Classification

SAE (Society of Automotive Engineers) grades classify oils by viscosity.
W grades (e.g. 0W, 5W, 10W): Low-temperature cranking viscosity (winter)
Summer grades (e.g. 20, 30, 40, 50): High-temperature viscosity

Multigrade Oils

5W-30, 10W-40, 15W-50: Multigrade oils satisfy *both* cold-start (W grade) and hot-running (summer grade) requirements.

Achieved by adding viscosity index improver polymers to a lower-grade base oil.

Vegetable and Animal Oils as Lubricants

Vegetable Oils

Castor oil	High viscosity; good boundary
Olive oil	Food-grade equip.
Palm oil	Textile machines

Pros: Renewable; biodegradable; good oiliness

Cons: Oxidize easily; gum formation; poor at high temp

Animal Oils

Lard oil	Watch, clocks
Sperm oil	Clocks, instruments
Fish oil	leather processing

Pros: Excellent boundary lubrication; natural EP

Cons: Oxidize fast; rancidity; limited temp range

Synthetic Lubricants

Why Synthetic Lubricants?

Designed molecules with precisely tailored properties; outperform mineral oils at extremes of temperature and load.

Type	Example	Application
Poly-α-olefins (PAO)	Mobil 1	Automotive engines; wide temp range
Polyol esters	Pentaerythritol ester	Jet engines, compressors
Phosphate esters	Skydrol	Fire-resistant hydraulic fluids
Silicones	PDMS	High-temp greases; inert with plastics
Polyglycols (PAG)	PEG-based	Compressors, gear boxes
Perfluoropolyethers	Fomblin	Vacuum pumps, space

Cutting Fluids (Metalworking Lubricants)

Purpose of Cutting Fluids

During machining operations (turning, drilling, milling): reduce friction at tool-workpiece interface, cool the cutting zone, and flush away chips.

Type	Composition	Best For
Straight oils	Mineral + EP additives	Heavy-duty; gear cutting, broaching
Soluble oils	Oil-in-water emulsion	General turning, grinding; good cooling
Semi-synthetic	Oil + water + additives	Versatile; low residue
Synthetic	Water + chemicals (no oil)	Grinding; maximum cooling

Key rule: High speed ⇒ prioritize cooling (water-based). High load ⇒ prioritize lubrication (oil-based).

Properties of Lubricants — Summary Table

Property	Test Method	What It Tells
Viscosity	Ostwald/Redwood	Flow resistance; film thickness
Viscosity Index	ASTM D2270	Temp sensitivity of viscosity
Flash point	Pensky-Martens	Max safe operating temp; impurities
Fire point	Cleveland open cup	Sustained ignition temp
Cloud point	ASTM D2500	Wax separation temperature
Pour point	ASTM D97	Low-temp flow limit
Acid value	Titration with KOH	Free acid content; oil degradation
Saponification no.	Reflux with KOH	Ester (fatty oil) content
Aniline point	ASTM D611	Aromatic content; rubber compatibility
Oiliness	Pin-on-disc friction	Boundary film formation ability

PYQ — 7-Mark Questions: Unit 5 Lubricants

Frequently Asked

1. Define lubricant. Explain its functions and classification. [7]
2. Explain viscosity and viscosity index with significance. [7]
3. Define flash point, fire point, cloud point, pour point with significance. [7]
4. Explain acid value and saponification number as properties of lubricants. [7]
5. Distinguish mineral oil, vegetable oil, and synthetic lubricants. [7]
6. Explain greases: composition, types, and uses. [7]
7. What are solid lubricants? Compare graphite and MoS_2. [7]
8. Explain the mechanisms of lubrication (hydrodynamic, boundary, EP). [7]

Unit 5 — Midpoint Summary

Topic	Key Point
Definition	Reduce friction, wear, heat; protect surfaces
Classification	Liquid, semi-solid (grease), solid
Mineral oil	Petroleum fraction; paraffinic or naphthenic
Grease	Oil + metallic soap; Li grease is multi-purpose
Solid lubricants	Graphite (needs moisture); MoS_2 (works in vacuum)
Viscosity	Most important property; measured in cSt
Viscosity Index	High VI = less change with temperature
Flash/Fire point	Safety; detect volatile impurities
Cloud/Pour point	Low-temperature performance
Acid value	mg KOH/g; indicates oil degradation
Saponification no.	mg KOH/g; indicates ester (fatty oil) content
Aniline point	Low AP = aromatic oil; swells rubber seals

Hydrodynamic Lubrication — Mechanism

Principle

At sufficiently high speed, a converging oil wedge builds up pressure between moving surfaces, completely **separating them with a fluid film**. No metal-to-metal contact occurs.

Conditions Required

Sufficient speed	Maintains the oil wedge pressure
Adequate viscosity	Too thin = film breaks; too thick = losses
Converging geometry	Oil dragged into the contact zone
Continuous oil supply	Must not starve

Examples: Journal bearings (crankshaft main bearings), thrust bearings, oil-film slider pads

Extreme Pressure (EP) Lubrication

When is EP Lubrication Needed?

Under very high contact pressures and shock loads (hypoid gear sets, heavily loaded cams) the oil film is squeezed out. EP additives are needed to prevent seizure.

How EP Additives Work

EP additives (S, P, Cl, or Zn compounds) react chemically with metal surface at the high interface temperature ($\sim$200–700°C) to form a sacrificial **iron sulfide / iron phosphide / iron chloride** layer.

This layer has **low shear strength** and prevents metal welding (scuffing/seizure).

Degradation of Lubricants in Service

Cause	Effect	Indicator
Oxidation	Acids, gum, varnish	High acid value; colour change
Thermal decomposition	Cracking; sludge	Viscosity change; dark colour
Water contamination	Emulsion; corrosion	Milky appearance; rust
Metal particles	Catalyse oxidation	Spectrometric analysis
Additive depletion	Loss of protection	High wear metals; AW depleted
Fuel dilution	$\downarrow$ viscosity	Flash point drops

Oil analysis (condition monitoring): Acid value, viscosity, particle count, spectroscopy — used to decide oil change interval.

Comparison of Lubricant Types

Feature	Mineral Oil	Vegetable Oil	Synthetic Oil
Source	Petroleum	Plants	Chemical synthesis
Oxidation stability	Good	Poor	Excellent
Temp range	-30 to 150°C	Limited	-60 to 300°C
VI	80–100	150–200	Up to 200$+$
Biodegradable	Moderate	Yes	Varies
Cost	Low	Low	High
Oiliness	Moderate	Excellent	Good
Main use	General engineering	Food, environment	Aerospace, extreme conditions

PYQ Short-Answer Practice (2-mark)

1. Define lubricant and state two functions.
2. What is viscosity index? Why is high VI important?
3. Define flash point and fire point. Which is higher?
4. Define cloud point and pour point.
5. What is acid value? Give its significance.
6. What is saponification number?
7. Define aniline point. What does low AP indicate?
8. What is oiliness? How does it differ from viscosity?
9. Compare graphite and MoS_2 as solid lubricants.
10. What is grease? Name its three main components.
11. What are EP additives? Give two examples.
12. Define boundary lubrication.

Numerical — Viscosity Index Calculation

Formula Recap

$$\text{VI} = \frac{L - U}{L - H} \times 100$$

L = kinematic viscosity of VI-0 reference oil at 40°C
H = kinematic viscosity of VI-100 reference oil at 40°C
U = kinematic viscosity of test oil at 40°C (same 100°C viscosity as reference oils)

Solved Example

Test oil at 40°C: U = 75 cSt; L = 120 cSt; H = 50 cSt

$$\text{VI} = \frac{120 - 75}{120 - 50} \times 100 = \frac{45}{70} \times 100 = \mathbf{64.3}$$

Stribeck Curve — Lubrication Regimes

The Stribeck Curve

A plot of **friction coefficient vs.** the Stribeck parameter $\eta N/P$ (viscosity $\times$ speed / load).

Region	Regime	Friction / Film
Low $\eta N/P$	Boundary	High friction; thin adsorbed film; wear
Intermediate	Mixed	Partial film; transition zone; decreasing friction
High $\eta N/P$	Hydrodynamic	Low friction; full fluid film; no wear

Minimum friction is in the hydrodynamic regime. Increase viscosity or speed to move from boundary toward hydrodynamic.

Grease Manufacturing

Process Overview

Grease = **base oil** (70–95%) + **thickener** (3–20%; metallic soap, clay, polyurea) + **additives**.

Metallic soap prepared by saponification: fatty acid + metal hydroxide → metal soap + water.

Example: $C_{17}H_{35}COOH + LiOH \rightarrow C_{17}H_{35}COOLi + H_2O$ (lithium stearate)

Drop Point

Drop point: Temperature at which grease loses its semi-solid structure and drips.
Calcium grease: $\approx$80°C | Sodium: $\approx$175°C | Lithium: $\approx$190°C | Bentonite: no drop point

Condition Monitoring of Lubricants

Why Monitor Lubricant Condition?

Regular oil analysis predicts machinery failure, optimizes oil-change intervals, and prevents costly breakdowns (predictive maintenance).

Test	Parameter	Indicates
Viscosity	cSt at 40°C	Dilution (fuel) or oxidation
Acid number (TAN)	mg KOH/g	Oxidation, acid buildup
Base number (TBN)	mg KOH/g	Remaining alkaline reserve
Particle count	ISO cleanliness	Wear, contamination
Elemental analysis	Fe, Cu, Al ppm	Wear of specific components
Karl Fischer water	ppm water	Water contamination

Bio-Lubricants and Green Lubrication

What are Bio-Lubricants?

Lubricants derived from **renewable biological sources** (vegetable oils, animal fats, synthetic esters from bio-based feedstocks). Designed for machinery in environmentally sensitive areas.

Advantages

- Rapidly biodegradable
- Non-toxic to aquatic life
- Renewable resource
- Excellent oiliness/lubricity
- High VI naturally

Limitations

- Poor oxidation stability (double bonds)
- Hydrolysis in presence of water
- High pour point (tropical oils)
- Higher cost vs mineral oils

Lubrication of Specific Machinery

Equipment	Lubricant Type	Key Requirement
Car engine	Multigrade oil (5W-30)	Wide temp range; detergency
Gear box	EP gear oil (GL-5)	High load; extreme pressure
Rolling bearing	Lithium grease	Low torque; water resistance
Hydraulic system	Hydraulic oil (ISO 46/68)	Good demulsibility; anti-wear
Turbines	Turbine oil	Excellent oxidation stability
Compressors	Compressor oil or PAG	Resist mixing with refrigerant
Food machinery	NSF H1 white oil	Non-toxic; food safe
Wire ropes	Bituminous compounds	Extreme pressure + corrosion resist

Numerical — Acid Value Determination

Formula

$$\text{Acid Value} = \frac{V \times M \times 56.1}{W} \quad \text{mg KOH / g oil}$$

where V = vol of KOH (mL), M = molarity of KOH, W = mass of oil (g), 56.1 = molar mass of KOH

Solved Example

2 g of oil titrated with 0.1 M KOH; 8.5 mL used to reach endpoint.

$$\text{AV} = \frac{8.5 \times 0.1 \times 56.1}{2} = \frac{47.685}{2} = \mathbf{23.84\ mg\ KOH/g}$$

(This is high; oil is significantly degraded and should be changed)

Unit 5 — PYQ Pattern Analysis

Topic	May 23	Nov 23	May 24
Viscosity + VI	7	3	7
Flash/Fire/Cloud/Pour point	7	7	3
Acid value + Saponification no.	3	7	7
Solid lubricants	3	3	3
Grease types	–	3	–
Mechanisms of lubrication	3	–	3
Classification of lubricants	–	–	7
Aniline point	3	3	3
Lubrication applications	3	–	–

Most likely 7-mark: Properties block (viscosity + VI + flash + fire + cloud + pour) **OR** acid value + saponification

Exam Tips — Unit 5: Lubricants

Do's

- State units for every property (cSt, mg KOH/g, °C)
- For acid value: mention significance (oil degradation)
- For saponification no.: mention what it measures (ester content)
- For VI: state high VI = better; mention why in engines
- For solid lubricants: distinguish graphite vs MoS_2 in vacuum

Don'ts

- Don't confuse acid value and saponification number
- Don't say graphite works in vacuum (it doesn't! MoS_2 does)
- Don't confuse flash point (momentary) and fire point (sustained)
- Don't say cloud point $>$ pour point (cloud $<$ pour, always)
- Don't write aniline point without stating rubber/seal implication

All Properties — At a Glance

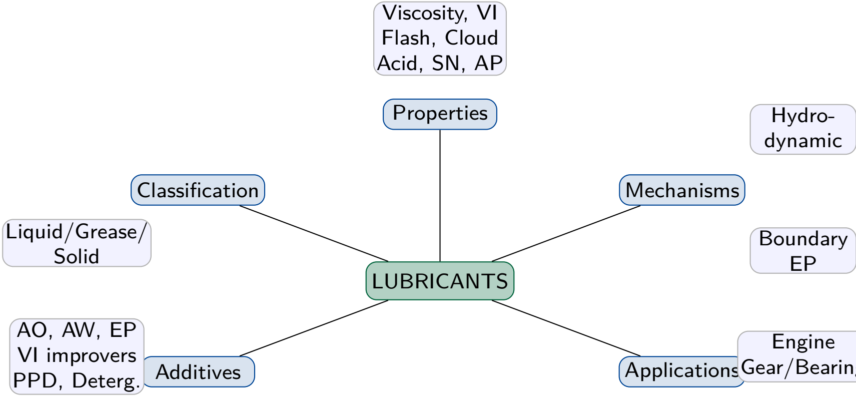
Property	High Value	Low Value
Viscosity	Too thick; power loss	Too thin; film failure
VI	Good (less temp effect)	Poor (varies widely)
Flash point	Safer; no impurities	Dangerous; volatile impurities
Fire point	Safer	Dangerous
Cloud point	Waxes crystallize early	Good low-temp clarity
Pour point	Solid at low temp	Good for cold climate
Acid value	Degraded, corrosive	Fresh, good quality oil
Saponification no.	High fatty oil content	Mostly mineral oil
Aniline point	Paraffinic; rubber-safe	Aromatic; attacks rubber
Oiliness	Good boundary film	May need additives

1. Test oil at 40°C: U = 95 cSt; L = 150 cSt; H = 60 cSt. Calculate VI.
2. 3 g oil titrated with 0.05 M KOH, 12 mL used. Calculate acid value.
3. 5 g oil saponified with 25 mL of 0.5 M KOH; back-titrated with 0.5 M HCl; 8 mL required. Find SN.
   (SN = (vol KOH − vol HCl equivalent) × M × 56.1 / mass of oil)
4. An engine oil has flash point 180°C and fire point 200°C. State whether it is safe to use at 175°C. Justify.
5. Explain why MoS_2 is preferred over graphite for space applications.

Unit 5 — Revision Flash Points

Key Fact	Value / Rule
Acid value units	mg KOH / g oil
Saponification no. units	mg KOH / g oil
VI formula	$(L-U)/(L-H) \times 100$
Fire point $>$ Flash point	Always true
Cloud point $<$ Pour point	Always true
Graphite in vacuum	Does NOT work (needs vapour)
MoS_2 in vacuum	Works well
Grease $=$	Oil $+$ metallic soap $+$ additives
Li grease drop point	$\approx$190°C
Low aniline point	High aromatics; swells rubber

Unit 5 — Lubricants Mind Map



Unit 5 — Complete Summary

Topic	Core Outcome
Definition	Substance reducing friction, wear, heat between moving parts
Liquid lubricants	Mineral (paraffinic/naphthenic), vegetable, animal, synthetic
Greases	Oil + soap + additives; Li grease most versatile
Solid lubricants	Graphite (needs moisture); MoS_2 (vacuum OK)
Mechanisms	Hydrodynamic $\rightarrow$ mixed $\rightarrow$ boundary $\rightarrow$ EP
Viscosity + VI	Flow resistance; high VI = stable with temp
Flash/Fire point	Safety; detect impurities
Cloud/Pour point	Low-temp performance limits
Acid value	Oil degradation (oxidation) indicator
Saponification no.	Ester/fatty oil content
Aniline point	Aromaticity; rubber seal compatibility

Viscosity: Numerical Examples

Problem 1

Dynamic viscosity of oil = 0.048 Pa · s
Density = 860 kg/m^3

Find: Kinematic viscosity

Solution:

$$\nu = \frac{\eta}{\rho} = \frac{0.048}{860}$$

$$\nu = 5.58 \times 10^{-5}\ \text{m}^2/\text{s}$$

$$= 55.8\ \text{cSt}$$

Problem 2

Kinematic viscosity at 40°C = 95 cSt
Kinematic viscosity at 100°C = 11 cSt

Compare to reference oil:
L (at 40°C for VI=0 oil) = 140 cSt
H (at 40°C for VI=100 oil) = 65 cSt

$$VI = \frac{L - U}{L - H} \times 100$$

$$= \frac{140 - 95}{140 - 65} \times 100 = \mathbf{60}$$

Key conversions: 1 Pa · s = 1000 mPa · s = 1000 cP; 1 m^2/s = 10 cSt; 1 cSt = 1 mm^2/s

Viscosity Index: ASTM Method Numerical

ASTM D2270 Method

Given: Oil viscosity at 40°C (U) = 72 cSt, at 100°C = 9.0 cSt
From ASTM tables for oils with viscosity 9.0 cSt at 100°C:
L = 119.0 cSt   H = 56.0 cSt

Formula: $VI = \frac{L - U}{L - H} \times 100 = \frac{119 - 72}{119 - 56} \times 100$

$VI = \frac{47}{63} \times 100 = \mathbf{74.6} \approx \mathbf{75}$

Interpretation:

- VI = 75 → Medium quality
- VI > 100 → Multigrade/synthetic
- VI < 40 → Naphthenic (poor)

VI Ranges:

VI	Quality
<40	Low
40–80	Medium
80–110	High
>110	Very High

Grease Consistency: NLGI Classification

NLGI Grades

NLGI	Penetration	Consistency
000	445–475	Semi-fluid
00	400–430	Fluid
0	355–385	Very soft
1	310–340	Soft
2	265–295	Normal (most common)
3	220–250	Medium firm
4	175–205	Firm
5	130–160	Hard
6	85–115	Very hard

Penetration Test:
Depth (in 0.1mm) a standard cone sinks in 5 seconds at 25°C

NLGI 2 most used for:

- Wheel bearings
- Electric motor bearings
- General purpose

NLGI 0/1 for:

Centralized grease systems, cold climates

Lubricant Selection Guide

Application	Lubricant Type	Key Property
High-speed spindles	Low viscosity oil	Low friction
Heavy gear boxes	EP gear oil (ISO 320)	High load bearing
Wheel bearings	NLGI-2 grease	Water resistance
Cylinder walls	Cylinder oil	Film strength
High temperature ovens	Silicone grease	Thermal stability
Food processing	White mineral / PTFE	Non-toxic
Wire ropes	Graphite grease	Penetration
Hydraulic systems	HLP hydraulic oil	Anti-wear
Compressors	Comp. oil (ISO 46)	Low carbon deposit
High vacuum pumps	Diffusion pump oil	Very low vapour pressure

Rule of thumb:

Higher speed $\rightarrow$ lower viscosity; higher load $\rightarrow$ higher viscosity/EP additive

Extreme Pressure (EP) Additives: Detailed

How EP Additives Work

Under extreme load → metal-to-metal contact → local temperature spike

EP additives react with metal surface at high temp to form:

- **FeCl** (from Cl-compounds)
- **FeS / Fe S** (from S-compounds)
- **FePO** (from P-compounds)

Low shear strength layer → prevents welding/scuffing

Common EP Compounds

- **Cl:** Chlorinated paraffins (active >180°C)
- **S:** Dibenzyl disulfide, ZDDP
- **P:** Tricresyl phosphate (TCP)
- **S+P:** ZDDP — Zinc dialkyldithiophosphate (most versatile)

ZDDP also acts as antioxidant + antiwear

Biodegradable & Eco-Friendly Lubricants

Why Biodegradable?

- Mineral oils persist in environment 100s of years
- EU Ecolabel requires >60% biodegradation in 28 days
- Marine, forestry, agricultural applications

Types:

- **Vegetable oils:** Rapeseed (HEAR), sunflower, soy — rapidly biodegradable
- **Synthetic esters:** Polyol esters, diesters — high performance + biodegradable
- **PAG (Polyalkylene glycol):** Water soluble, low toxicity

Comparison

Property	Mineral	Bio-bas
Biodegradation	<30%	>60%
VI	95–110	150–22
Pour point	−15°C	−10 to −
Oxidation stability	Good	Fair
Cost	Low	High

Automotive Lubricants: Engine Oil Grades

SAE Viscosity Grades

Monograde: SAE 30, SAE 40 (summer only)
Multigrade: SAE 10W-40
10W = cold cranking at −20°C
40 = viscosity at 100°C

Grade	Application
5W-30	Small cars, fuel economy
10W-40	Passenger cars (standard)
15W-40	Diesel engines, trucks
20W-50	Older engines, hot climate

API Service Classification

Gasoline engines (S-series):
SN/SP → latest; SM, SL → older

Diesel engines (C-series):
CK-4 → latest heavy duty

Additives in engine oil:

- Detergents (clean deposits)
- Dispersants (suspend soot)
- ZDDP (anti-wear)
- VI improvers (multigrade)
- Antioxidants

Industrial Gear Oils & Hydraulic Fluids

Industrial Gear Oils

ISO Grades: 68, 100, 150, 220, 320, 460, 680

Types:

- CLP (EP gear oil) — most common for enclosed gears
- HVI (high VI) — temperature variable applications
- SHC (synthetic) — extreme temp/load

Selection: higher speed→lower ISO grade; gear tooth sliding→EP additive

Hydraulic Fluids

ISO HM (anti-wear) and HLP (anti-wear+rust)

Key properties:

- Low compressibility
- Good VI (> 95)
- Anti-wear additives (ZDDP)
- Anti-foam agents
- Rust/oxidation inhibitors

Common grades: ISO 32, 46, 68
Fire-resistant fluids: HFA/HFB/HFC/HFD for mining

Previous Year Questions: Short Answer (Unit 5)

2-mark Questions:

1. Define viscosity index. What does a high VI indicate?
2. Distinguish flash point and fire point.
3. What is the role of EP additives?
4. Differentiate cloud point and pour point.
5. What is acid value of a lubricant?
6. Define saponification number.
7. State two functions of a lubricant.
8. What are solid lubricants? Give two examples.

3-mark Questions:

1. Explain hydrodynamic lubrication with diagram.
2. How is viscosity index measured?
3. Distinguish mineral and synthetic lubricants.
4. What is boundary lubrication? When does it occur?
5. Explain pourpoint depressants.
6. Compare grease and oil as lubricants.

Previous Year Questions: 7-Mark (Unit 5)

Descriptive Questions (7 marks each)

1. Explain in detail the various properties of lubricating oils with their significance. *(Flash pt, Fire pt, Cloud pt, Pour pt, VI, Aniline pt, Acid value)*
2. Describe the different mechanisms of lubrication. How does hydrodynamic lubrication differ from boundary lubrication?
3. What are synthetic lubricants? Discuss PAO, ester-type and silicone lubricants with advantages over mineral oils.
4. Classify lubricants. Explain greases — their composition, types and applications.
5. Discuss the role of various additives used in lubricating oils with examples.
6. Write a note on solid lubricants: graphite and MoS — structure, properties and applications.
7. Compare mineral oil, vegetable oil and synthetic lubricants on the basis of properties and applications.

Numericals Practice Set (Unit 5)

Practice Problems

Q1. Dynamic viscosity of oil = 0.065 Pa · s, density = 890 kg/m^3. Find kinematic viscosity in cSt.

Q2. U (at 40°C) = 85 cSt. L = 125 cSt, H = 50 cSt (ASTM table). Calculate Viscosity Index.

Q3. An oil has flash point 180°C and fire point 200°C. State significance of each.

Q4. Cloud point of oil A = −10°C, pour point = −15°C. Cloud point of oil B = −5°C, pour point = −12°C. Which oil is better for cold climate use?

Q5. 1 g of oil requires 2.5 mL of 0.1N KOH for neutralization. Find acid value.

Answers: Q1: 73.03 cSt Q2: VI = 53.3 Q3: Flash pt → fire hazard; fire pt → sustained combustion Q4: Oil A (lower pour pt) Q5: AV = 2.5 × 0.1 × 56.1 / 1 = 14 mg KOH/g

Common Exam Errors & Tips (Unit 5)

Common Mistakes

- Confusing flash point (vapour ignites momentarily) with fire point (sustained burning)
- Saying high VI = high viscosity (Wrong! VI = stability of viscosity with temperature)
- Cloud point > pour point (always cloud pt is higher)
- MoS acts as lubricant due to weak van der Waals between layers, NOT ionic bonds
- Saying all greases are soap + mineral oil — some use synthetic oil or non-soap thickeners

Scoring Tips

- Always define before explaining property
- Draw Stribeck curve for 7-mark lubrication mechanism Q
- For properties table Q: at least 6–7 properties with definition + significance
- Hydrodynamic lubrication: mention wedge film formation
- Grease Q: always mention thickener (soap) + base oil + additives
- EP lubricant: always mention chemical film formation at high temperature

Revision Flash Points: Unit 5 Key Facts

Property / Term	Key Fact
Viscosity units (dynamic)	$Pa \cdot s$ or cP ($1\ Pa \cdot s = 1000$ cP)
Viscosity units (kinematic)	m^2/s or cSt ($1\ m^2/s = 10$ cSt)
High VI oil	Viscosity changes less with temperature
Flash point	Temp at which vapour momentarily ignites
Fire point	Temp at which oil sustains burning (>flash pt)
Cloud point	Temp at which wax crystals first appear
Pour point	Temp below which oil stops flowing (cloud pt > pour pt)
Acid value	mg KOH to neutralize 1 g oil (measures acidity)
Saponification No.	mg KOH to saponify 1 g oil (measures ester content)
NLGI 2 grease	Most common; penetration 265–295 × 0.1 mm
MoS lubricant	Layered hexagonal structure; weak van der Waals
Graphite lubricant	Good conductor; works in humid conditions
EP additives	Form sacrificial chemical film at

Lubricating Oil: Key Properties & Typical Values

Property	Typical Range	Significance
Viscosity @ 40°C	15–680 cSt	Film thickness; load carrying
Viscosity @ 100°C	3–100 cSt	High-temp performance
Viscosity Index	80–150+	Temp sensitivity of viscosity
Flash Point	150–320°C	Fire safety, volatility
Pour Point	-50 to -5°C	Cold start performance
Cloud Point	-40 to 0°C	Wax separation in cold
Acid Value	<0.1 (new oil)	Acidity/corrosiveness
Saponification No.	Varies	Ester content
Aniline Point	70–120°C	Aromatic content, rubber compatibility
Density @ 15°C	840–900 kg/m^3	Quality indicator

Used oil analysis monitors these values — significant change indicates degradation or contamination

Unit 5: Summary & Bridge to Unit 6

Unit 5 Covered

- ✓ Definition, functions, classification
- ✓ Liquid, semi-solid, solid lubricants
- ✓ Lubrication mechanisms (HD, EHD, boundary, EP)
- ✓ All key properties (viscosity, VI, flash/fire/cloud/pour pt, acid value, saponification No.)
- ✓ Additives: VI improvers, EP, antioxidants, detergents
- ✓ Automotive + industrial applications
- ✓ Biodegradable lubricants
- ✓ PYQ + numericals

Next: Unit 6 — Polymers

Topics Ahead:

- Polymer definition & classification
- Addition vs Condensation polymerization
- Thermoplastics vs Thermosets
- Important polymers: PE, PP, PVC, Nylon-66
- Elastomers: Natural rubber, Buna-S, Neoprene
- Conducting polymers: PANI
- Biodegradable polymers
- Fiber-reinforced composites