Industrial Lubricants

Performance you can rely on.

Industrial lubricants: a diverse market of nearly 12 million tons

- Process Oil, 2,180 kt
- Hydraulics, 3,500 kt
- R & O, 1,300 kt
- Metalworking, 2,200 kt
- Compressor, 450 kt
- Turbine, 600 kt
- Grease, 720 kt
- Industrial Gear, 920 kt
Fluid types

- Hydraulic fluids
- Metalworking fluids
- Grease
- Compressor fluids

Hydraulic fluids

- Applications
- Specifications
- Formulation
- Trends
Hydraulics vs transmissions

- A transmission adapts the output of the internal combustion engine to the drive wheels
  - The transmission fluids lubricate and cool while also operating at cold temperatures (for cold morning starts). Will provide corrosion protection, prevents deposits, and used to remove of any debris within the transmission
- A hydraulic system transfers energy through the flow of pressurized liquid.
  - The Hydraulic fluids not only lubricate and cool but are the actual fluid producing the power through a pump by different pressure and flow.

Simplified hydraulic system
Hydraulic system components

- Pump: converts mechanical energy to fluid power
  - Different types, often mixed within a system
- Actuators (cylinders/motors): convert fluid power to linear or rotary motion
- Valves: control system pressure and flow
- Filters: remove solid contaminants
- Hoses: distribute fluid
- Seals: contain fluid and block contaminants
- Reservoir: stores fluid, enables dissipation of heat/air and separation of water
- Accumulators: dampen pump pulsations
- Hydraulic fluid

Lubricating functions of hydraulic fluid

- Transfer power (it must be a non-compressible fluid)
- Maintain proper lubricating viscosity (resist oxidation/shear)
- Lubricate and protect moving parts
  - Pumps
  - Valves
  - Bearings
- Carry heat and contaminants to sump and filter
- Prevent deposits formation on moving parts
- Prevent foam, rust/corrosion, emulsion
- Maintain seal condition
Gear pumps

Vane pumps
Axial piston pumps

Many types of hydraulic fluid to fit many applications

• Mineral oil based fluids
  – Wide operating range and medium cost
    (general purpose, mobile)
• Oil in water emulsions
  – Fire resistant and low cost (mining)
• Water in oil emulsions, water-glycol solutions
  – Fire resistant with good viscosity
    (steel industry, marine)
• Synthetic/bio-based fluids (many types)
  – Phosphate esters: fire resistant, wide operating range (aerospace)
  – Polyol esters: biodegradable (forestry)
Fire resistant hydraulic fluids

- ISO 6743-4 defines classes of Fire Resistant Hydraulic Fluids (FRHF) by their formulation; fluid selection must consider a number of trade-offs

<table>
<thead>
<tr>
<th>Property/class</th>
<th>HFAE oil in water</th>
<th>HFB water in oil</th>
<th>HFC water / glycol</th>
<th>HFDR phos. ester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%)</td>
<td>~ 95</td>
<td>~ 40</td>
<td>~ 40</td>
<td>0</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>Excellent</td>
<td>Good</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Lubricity</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
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<tr>
<td>Temperature range</td>
<td>5 / 50 °C</td>
<td>5 / 50 °C</td>
<td>-20 / 50 °C</td>
<td>-20 / 65 °C</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Very low</td>
<td>Medium</td>
<td>Medium/high</td>
<td>High</td>
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</table>

Specifications and standards

- Key OEM specifications include
  - Parker Hannifin HF-0
  - Eaton ATS-373
- ISO and ASTM D-6973 standards
- National standards (DIN, BSI, AFNOR)
- End-user specifications (GM LS-2, MAG P-series)
- Many fluids will meet most of these specifications
### Hydraulic fluids key performance tests

<table>
<thead>
<tr>
<th>Performance/test</th>
<th>P. H. HF-0</th>
<th>MAG P-70</th>
<th>ASTM D6158</th>
<th>GM LS-2 LH-04</th>
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<tr>
<td>Pump wear</td>
<td>TGH20C</td>
<td>35VQ25</td>
<td>D2882</td>
<td>D7043</td>
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<td></td>
<td></td>
<td></td>
<td>35VQ25</td>
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<tr>
<td>Oxidation</td>
<td>D4310</td>
<td>D4310</td>
<td>D943</td>
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<td></td>
<td>D943</td>
<td>D4310</td>
<td></td>
<td>D943</td>
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<tr>
<td>Thermal stability</td>
<td>C.M. (proc A)</td>
<td>C.M. (proc A)</td>
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<td>D2070</td>
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<tr>
<td>Hydrolytic stability</td>
<td></td>
<td></td>
<td></td>
<td>D2619</td>
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<tr>
<td>Demulsibility</td>
<td>D1401</td>
<td>D1401</td>
<td>D1401</td>
<td>D1401</td>
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<tr>
<td>Air release</td>
<td>D3427</td>
<td>D3427</td>
<td></td>
<td>D3427</td>
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<tr>
<td>Filterability</td>
<td>TP-02100</td>
<td></td>
<td></td>
<td>TP-02100</td>
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<tr>
<td>Other</td>
<td>D665</td>
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<td>D130</td>
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### Typical formulations

<table>
<thead>
<tr>
<th></th>
<th>Rust and oxidation inhibited type (mass%)</th>
<th>Antwear type (mass%)</th>
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<tbody>
<tr>
<td>Oil / package</td>
<td>0.3 - 0.5</td>
<td>0.6 - 0.8</td>
</tr>
<tr>
<td>Antweaer</td>
<td></td>
<td>60 - 70</td>
</tr>
<tr>
<td>Antioxidant</td>
<td>75 - 85</td>
<td>15 - 25</td>
</tr>
<tr>
<td>Dispersant / stabilizer</td>
<td>5 - 10</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Rust inhibitor (ferrous)</td>
<td>5 - 10</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Corrosion inhibitor (copper)</td>
<td>2 - 5</td>
<td>0.1 - 0.5</td>
</tr>
<tr>
<td>Demulsifier</td>
<td>0.2 - 0.5</td>
<td>0.01 - 0.02</td>
</tr>
<tr>
<td>Antifoamant</td>
<td>0.01 - 0.02</td>
<td>0.01 - 0.02</td>
</tr>
<tr>
<td>Pour point depressant</td>
<td>0.1 - 0.5</td>
<td></td>
</tr>
<tr>
<td>Mineral oil</td>
<td>Balance</td>
<td>Balance</td>
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Viscosity classifications

Hydraulic fluids use the ISO 3446 viscosity classification system

<table>
<thead>
<tr>
<th>ISO VG grade</th>
<th>Mid-point viscosity, cSt at 40°C</th>
<th>Viscosity, cSt at 40°C</th>
<th>Mid-point viscosity, cSt at 40°C</th>
<th>Viscosity, cSt at 40°C</th>
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<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>ISO VG grade</td>
<td>Min</td>
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<tr>
<td>2</td>
<td>2.2</td>
<td>1.98</td>
<td>2.42</td>
<td>100</td>
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<td>3</td>
<td>3.2</td>
<td>2.88</td>
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<td>150</td>
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<td>5</td>
<td>4.6</td>
<td>4.14</td>
<td>5.06</td>
<td>220</td>
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<td>7</td>
<td>6.8</td>
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<td>7.48</td>
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<td>10</td>
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<td>9.00</td>
<td>11.0</td>
<td>460</td>
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<td>15</td>
<td>15</td>
<td>13.5</td>
<td>16.5</td>
<td>680</td>
</tr>
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<td>22</td>
<td>22</td>
<td>19.8</td>
<td>24.2</td>
<td>1000</td>
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<tr>
<td>32</td>
<td>32</td>
<td>28.8</td>
<td>35.2</td>
<td>1500</td>
</tr>
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<td>46</td>
<td>46</td>
<td>41.4</td>
<td>50.6</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>68</td>
<td>61.2</td>
<td>74.8</td>
<td></td>
</tr>
</tbody>
</table>

* A particular grade expressed as, e.g., ISO VG 46

Hydraulic fluid selection criteria/considerations

- Type of pumps used in system
- OEM recommendation
- Operating conditions/temperature range
- Environmental factors
- Materials of constructions (seals)
- Anticipated leakage rate
Trends affecting hydraulic fluids

- Increasing power density (do more with less)
- Enhanced thermal and oxidative stability
- Improved hydrolytic stability and wet filtration capability
- Growing demand for biodegradable fluids due to regulatory and/or environmental drivers
- Increased demand for ashless additives

Metalworking fluids

- Applications
- Formulation
- Trends
Metalworking fluid applications

- Distinguishing feature of metalworking fluids is they lubricate both machine/tool and work piece
- Metalworking fluids lubricate, clean and prevent rust at metal/tool interface
- Metalworking fluid types differentiated by machining task
  - Cutting oils: drilling, turning, grinding, etc.
  - Rolling oils: steel, aluminum (hot or cold)
  - Quenching Oils: High strength steel typically
  - Preservatives: temporary, permanent
  - Deformation Oils: drawing, forming, etc.

Metalworking fluid functions

- Different metalworking tasks share common lubrication requirements, but stress some relative to others:
  - Cooling: all, except preservatives, especially cutting oils and rolling oils
  - Swarf removal: all, except preservatives, especially cutting oils
  - Wear Protection: all, except preservatives, especially cutting oils
  - Corrosion protection: all
  - Rust protection: especially preservatives
  - Extend tool life: all except preservatives, especially cutting oils
Metalworking fluids are matched to the application

- Cutting oil application severity driven by two main considerations
  - Operational severity
  - Machinability of material

Operational severity

<table>
<thead>
<tr>
<th>Tapping, threading</th>
<th>Gear cutting</th>
<th>Boring</th>
<th>Milling</th>
<th>Planning</th>
<th>Turning</th>
<th>Sawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing severity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Material machinability

<table>
<thead>
<tr>
<th>Titanium alloys</th>
<th>Inconel</th>
<th>Stainless steel</th>
<th>Steel</th>
<th>Cast iron</th>
<th>Aluminum alloys</th>
<th>Brass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing severity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Metalworking formulation affected by several factors

- Metalworking fluids, except preservatives, formulated for
  - Cooling:
    - Allows increased production rates; extends tool life; minimizes corrosion

  - Wear protection:
    - Extends tool life; improves surface finish

  - Local conditions:
    - Water quality; waste disposal

- Oil-in-water emulsions dominate because of low cost and superior cooling; additives optimized for specific applications
Metalworking fluid types

- **Straight Oils**
  - Petroleum, synthetic, seed oil, solvent
- **Emulsifiable Oils**
  - Petroleum, Ester, Synthetic Hydrocarbon
- **Semi-synthetic (Preformed Emulsions and Pastes)**
- **Water Based Synthetic**
- **Seed Oil Based - Emulsifiable**
- **Dry Film Lubricants**
- **Prelubes**
- **Blankwasher Fluids**
  - Water, oil, solvent based

Metalworking base materials

- **Carriers**
  - Water
  - Mineral Oil
    - Paraffinic, Naphthenic
  - Synthetic Hydrocarbon
    - Polybutene
    - PAO
  - Vegetable Oils (seed oils)
  - Synthetic Esters
    - Methyl esters
    - Polyol esters
    - Petroleum Distillates
## Metalworking typical additives

- **Emulsifiers (To emulsify in water or ease of cleaning)**
  - Anionic
    - Sulfonates, carboxylates, phosphates, Sulfates
  - Nonionic
    - Alcohol ethoxylates, amides
  - Amphoterics and Cationics (not common)
- **Corrosion Inhibitors (Oil and Waterbased)**
  - Sulfonates, carboxylates, borates, phosphates, oxidized waxes, alkanolamines
- **Metal Passivators (Oil and Waterbased)**
  - Triazoles, thiazoles, thiadiazoles

## Metalworking typical additives

- **Alkalinity**
  - Alkanolamines, metal hydroxides (Water)
    - TEA, MEA, DGA, DEA, AMP-95, KOH, NaOH
- **Lubricating**
  - Boundary, mixed film
    - Fatty acid soaps, esters, alcohols, polymers
  - Extreme Pressure
    - Reactive
      - Chlorine, sulfur, and phosphorous bearing, organometallics (Zn and Mo)
    - Inert Solid Lubricants
      - Calcium carbonate, mica, talc, graphite, molybdenum disulfide
    - Overbased Calcium and Sodium Sulfonates
Metalworking typical additives

- Antimist, thickeners, tackifier
  - Polymers
- Dispersants
  - To suspend solids in product and/or during use (PIBSAs)
- Antioxidants
  - Hindered phenols and aromatic amines
- Anti-Foam: Non-polydimethylsiloxane (PDMS)
  - Stearamide wax, modified PDMS, surfactants
- Antimicrobial
  - Biocides and Fungicides
- Couplers
  - Glycol ethers, glycols, alcohols, diacids
- Dyes, Fragrances

Metalworking fluid formulations

<table>
<thead>
<tr>
<th>NEAT OILS:</th>
<th>SOLUBLE OILS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>Oil</td>
</tr>
<tr>
<td>Lubricity/EP Additives</td>
<td>Anticorrosion</td>
</tr>
<tr>
<td>VI Improvers/AO/Antimist</td>
<td>Emulsifiers</td>
</tr>
<tr>
<td>Anticorrosion</td>
<td>Antimist</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SEMI-SYNTHEHTICS:</th>
<th>SYNTHETICS:</th>
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</thead>
<tbody>
<tr>
<td>Oil</td>
<td>WATER</td>
</tr>
<tr>
<td>Emulsifiers</td>
<td>Anticorrosion</td>
</tr>
<tr>
<td>Anticorrosion</td>
<td>Lubricity/EP Additives</td>
</tr>
<tr>
<td>Lubricity/EP Additives</td>
<td>Biocide/Fungicide</td>
</tr>
<tr>
<td>Biocide/Fungicide</td>
<td>Coupling Agents/Antifoam</td>
</tr>
<tr>
<td>WATER</td>
<td>WATER</td>
</tr>
</tbody>
</table>

Components listed in volume order
Elements of oil-in-water emulsions and additives

• Fluid typically consists of 90-98% water
  – Milky emulsions contain 3-10% oil concentrate
  – Micro emulsions contain 2-5% oil concentrate

Metalworking fluid trends

• Product evolution to meet end-user needs
  – Optimized for manufacturing process, material and tool changes
    • Heat tolerant
    • Longer life fluids
      – In-use and on-part
    • Waterbased to oil
    • Oil to waterbased
    • Dry film lubricants
  – Seed oil based products

• Reformulation / Raw material substitutions
  – For cost
  – Raw material availability
    • Base Oil Trends: Group 1 to Groups 2, 3 & 4
  – For HS&E reasons
    • Chlorinated paraffin, triazine, Secondary Amines, Boron
Greases

• Applications
• Specifications
• Formulation
• Trends

Greases have several unique characteristics

• Grease is a two phase lubricant: a thickener dispersed in a liquid lubricant

• Thickener dispersions are processed to maximize oleophilic (oil loving) surface area, leading to stable dispersions

• Greases characterized by
  – Very high film strength
  – Low yield strength
  – Ability to block contaminants (dirt, water)
  – High stickiness/ability to stay in place
  – A different vocabulary
Greases facilitate lubrication in special applications

• Sealed and packed bearings

• Low speed, highly loaded gears

• Jack screws, worm drives

• Hinges and joints
  – Lubricant stays in place
  – Contaminants are kept out
  – Low yield strength allows efficient rotation

Lubricating functions of grease

• Within a grease, the lubricant and thickener phases serve (mostly) different functions

• Lubricant phase
  – Lubricate moving parts
  – Provide antwear, EP protection
  – Provide rust and corrosion protection
  – Prevent oxidation/thermal degradation

• Thickener phase
  – Maintain consistency
  – Provide stay-in-place and adhesive characteristics
  – Keep water and contaminants out

• A variety of thickeners can be used which provide a balance of varying characteristics
North America grease production by thickener type

- Polyurea, 6.4%
- Organophilic clay, 5.4%
- Aluminum complex, 9.3%
- Other thickeners, 3.9%
- Calcium sulfonate, 4.0%
- Anhydrous calcium, 1.3%
- Hydrated calcium, 1.2%
- Conventional lithium, 35.2%
- Lithium complex, 35.2%

Metal soaps are most common thickener type

- Metal soap thickeners most often created by neutralizing a fatty acid (e.g. 12-hydroxystearic acid) with metal (calcium, sodium, aluminium, lithium)
  - Metal soap thickeners crystallize as webs of tangled fibers
- Complex greases utilize both fatty and non-fatty acids, neutralized with metal
- Clay greases utilize amines and polar activators to produce stable dispersions of oleophilic platelets
- Alkyl amines can be processed to generate stable dispersion of chain-like polyurea thickener
- Each thickener type produces a different set of physical properties
Performance properties

- **Dropping Point**: Temperature at which it passes from a semi-solid to a liquid state under specific test conditions. Becomes fluid enough to drip
- **Penetration**: Measured by cone of given weight and allowed to sink into a grease for five seconds at temp of 25°C. (Worked and unworked grease)
- **Water Resistance**: Ability of a grease to withstand the effects of water with no change in its ability to lubricate
- **Pumpability**: Ability of grease to be pumped or pushed through a system
- **High and low temperature effects**: High temperatures induce softening or bleeding. Low temperatures cause torque limitations, too high viscosity and alter pumpability

Grease thickener types and their key properties

<table>
<thead>
<tr>
<th></th>
<th>Metal soaps</th>
<th>Complex</th>
<th>Non-soap</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Calcium</td>
<td>Lithium</td>
<td>Clay</td>
</tr>
<tr>
<td>Dropping point, °C</td>
<td>~100</td>
<td>~190</td>
<td>&gt;260</td>
</tr>
<tr>
<td>Stability</td>
<td>Good</td>
<td>Exc.</td>
<td>Fair</td>
</tr>
<tr>
<td>Water resistance</td>
<td>V. Good</td>
<td>Good</td>
<td>Exc.</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Poor</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Cost (relative)</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>
Grease classification by consistency

- National Lubricating Grease Institute (NLGI) classifies grease by hardness using cone penetration

<table>
<thead>
<tr>
<th>NLGI #</th>
<th>Penetration (x 0.1 mm)</th>
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<tbody>
<tr>
<td>000</td>
<td>445 - 475</td>
</tr>
<tr>
<td>00</td>
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<td>5</td>
<td>130 - 160</td>
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<tr>
<td>6</td>
<td>85 - 115</td>
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Diverse applications limit performance standards

- ASTM D4950 classifies grease by application and by performance level
  - Type G for bearings; type L for chassis
  - Sub-types A,B,C denote increasing performance

<table>
<thead>
<tr>
<th>Property</th>
<th>GA</th>
<th>GB</th>
<th>GC</th>
<th>LA</th>
<th>LB</th>
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</tr>
<tr>
<td>Low-temperature torque</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>
Grease additives vary by application

- Additives (10 – 20% mass typical treat rate) commonly utilized in grease include:
  - Thickener: all grease; selection based on trade-offs; typical treat rate 7-16%
  - Tackifiers: high-speed and hinge/joint applications
  - Antioxidants: most greases, especially bearing and sealed-for-life applications
  - Antiwear/EP: gear and bearing applications
  - Rust/corrosion inhibitors: most applications, especially automotive for rust
  - Viscosity modifiers: temperature extremes

Grease trends

- Continued shift to higher performance and higher temperature products
- Increased use of synthetic grease in low/high temperature services and in sealed-for-life systems
- Continued consolidation and reduction of grades in service
- Increased competition from dry lubricants in ultra-severe environments
Compressor fluids

• Applications
• Specifications
• Formulation
• Trends

Compressor fluid requirements driven by compressor design

• Dynamic compressors
  – Essentially turbines
  – No lubricant/gas contact
  – Minimal anti-wear/EP
  – Maximum thermal stability
Compressor fluid requirements driven by compressor design

- Reciprocating compressors
  - Piston and diaphragm
  - Some lubricant/gas contact
  - Moderate antiwear/EP
  - High oxidation stability

- Rotating compressors
  - Sliding vane, rotary screw, rotary lobe, etc.
  - Highest lubricant/gas contact, especially in flooded systems
  - Lubricant/process gas insolubility is critical
  - Highest antiwear/EP
Lubricating functions of compressor fluid

- Lubricate and protect moving parts
  - Pistons, vanes
  - Bearings
- Remove heat of compression, especially in flooded systems
- Maintain system cleanliness
- Prevent foam, rust/corrosion, emulsion
- Maintain fluid viscosity (resist oxidation)
- Provide liquid seal between compression chambers

Industry and OEM performance standards

- For general duty air service, DIN 51506 defines a basic standard of performance for reciprocating air compressor lubricants
- OEM service fill recommendations are generally vague: “Use a high quality rust and oxidation inhibited mineral oil.”
- OEM factory fill and genuine oils typically based on proprietary specifications
- Key OEMs include
  - Atlas-Copco  Sullair  Quincy
  - Doosan  Dresser Clarke  Gardner-Denver
Compressor tests

- Oxidation/thermal stability
  - Oxidation/corrosion stability (FTM 5307)
  - Hydrolytic stability (FTM 3457.2)
  - Rotating pressure vessel oxidation (D2272)
- Wear protection
  - 4 ball wear (D2596)
  - 4 ball EP (D2783)
- Rust/corrosion
  - Rust (D665A/B)
  - Copper corrosion (D130)
- Foam/demulsibility
  - Foam (D892)
  - Demulsibility (D1401)

Process gas – compressor fluid interactions drive base stock selection

- Key interactions/considerations
  - Solubility of process gas in fluid
    - Causes loss of viscosity
  - Reaction between process gas and fluid
    - Can cause gas contamination, fire, explosion
  - Solubility of fluid in process gas
    - Can cause gas contamination, loss of fluid
- Mineral oil suitable for inert gases
- Synthetics required for hydrocarbons and reactive gases
Refrigeration compressors require unique lubricants

- Refrigeration cycle and design require a lubricant balancing unique properties

- Low solubility of refrigerant gas in lubricant
  - High miscibility between liquid refrigerant and lubricant
  - Low reactivity between refrigerant gas and lubricant
  - No deposits formation

Refrigeration compressor formulation

- Lubrication requirements with common refrigerants favor non-additized synthetics, although naphthenic base stocks still used in certain applications

- Refrigerant determines base stock type
  - Ammonia: alkylbenzene, PAGs
  - Hydrocarbons: esters, PAGs
  - CO2: esters, PAGs
  - HFC: polyol esters, PAGs
  - HCFC: naphthenics, alkylbenzene, polyol esters
  - CFC: naphthenics, alkylbenzene
Compressor fluid trends

• Do more with less (longer drain intervals, smaller sumps, higher temperatures)

• Increased utilization of high quality (Group II/III base stocks in addition to PAO)

• Replacement of chlorinated refrigerants (CFC, HCFC) with more 'ozone-friendly' types (HFC), and resultant changes in preferred base stock type