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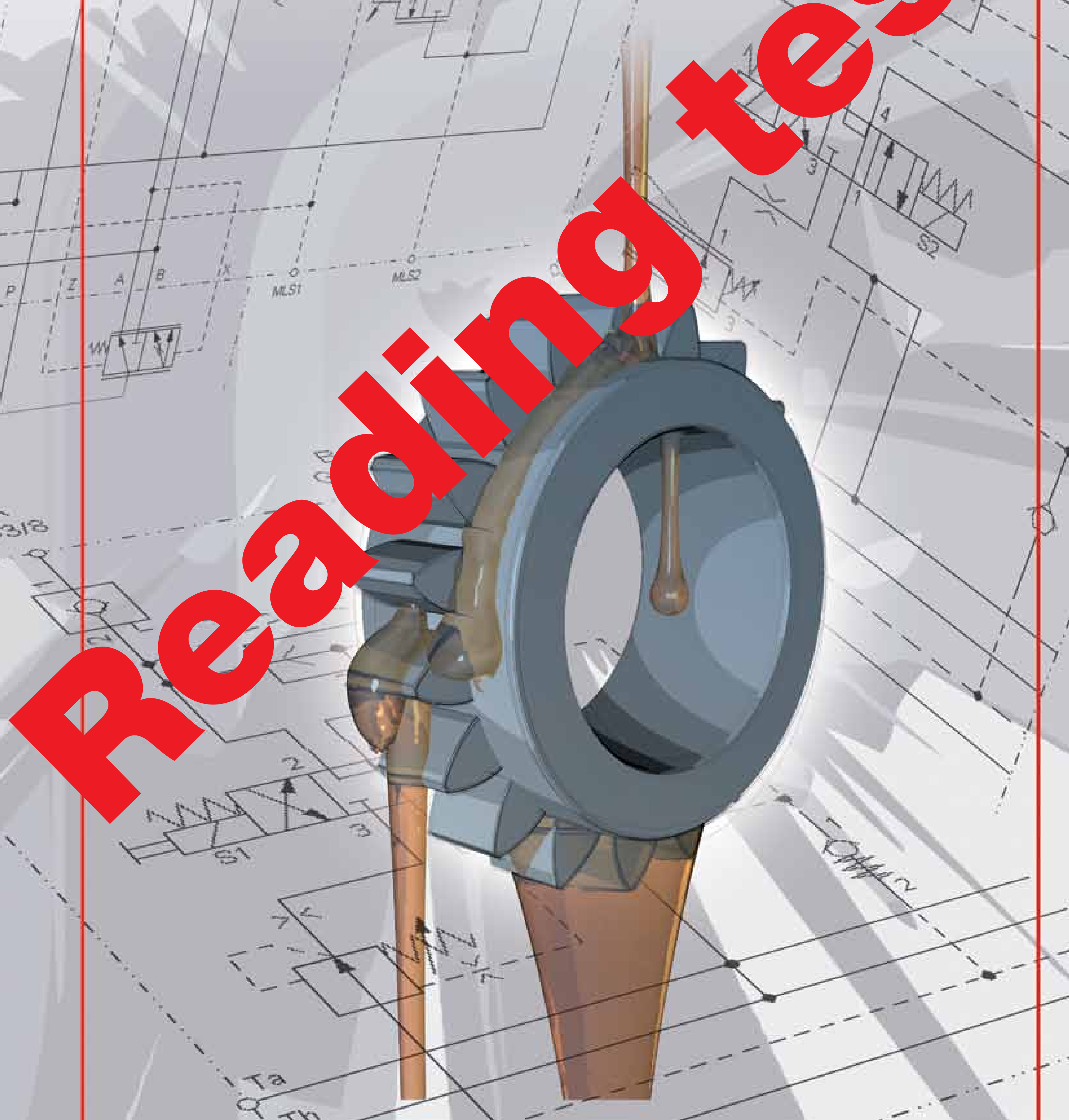
Operating fluids for stationary and mobile lubrication and hydraulic systems



Operating fluids for stationary and mobile lubrication and hydraulic systems

Author	Martin Reik, Grad. Eng.
Editors	Susanne Lingemann, Melanie Gelf

Publisher HYDAC Systems & Services GmbH
Training Center
Hirschbachstraße 2
D-66280 Sulzbach/Saar
E-mail: E-learning@HYDAC.com
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Preface

The safe and dependable operation of stationary equipment, such as transfer lines, machining centers, presses and paper machinery, or heavy industrial and mobile equipment, such as excavators, wheel loaders and bulldozers, is possible only through the use of operating fluids adapted to the respective application.

These operating fluids are a vitally important component, representing one of the most important, yet often one of the most neglected design elements in the system. Their properties and condition are decisive for the service life and the degree of effectiveness of the, usually expensive, components used in the equipment, as well as in the overall system.

The most important and essential knowledge about operating fluids is usually available only superficially to the persons stipulating and planning the desired equipment functions.

Similarly, improper equipment maintenance can negatively affect the characteristics of the operating fluids deployed. Dependable and specific operating fluid maintenance measures make possible longer retention times for the operating fluid in the equipment along with an increase on component operating lives. Downtimes for maintenance and repairs are reduced.

This book provides an in-depth look at the subject matter. In so doing, the author deals with the composition, the characteristic values and the standards of operating fluids and greases.

The author would like to thank Mr. Bock, Fuchs Co., Mr. Spilker, Total Co., Mr. Lämmle, Panolin Co. and Mr. Thieme for their professional advice.

Notes:

1 Introduction

1.1 General

The Egyptians were already aware that the construction of pyramids without the use of operating fluids was only possible with high material and physical losses. Without the olive oil applied to heavy stones and wooden beams as "operating fluid", it would not have been possible to keep to the construction times specified by the Pharaoh.
Up to the beginning of the 19th century, operating fluids were obtained from plants and animals such as for example olives, oilseed rape, castor oil plant seeds and fruits of the oil palm for lubricating bearings and for slow-running machines. The invention of the steam engine in 1765 meant that these organic, animal and vegetable lubricants proved insufficient and had to be replaced with mineral oils.
The disadvantage of these organic and mineral oils was mainly that they differed immensely in quality. The production of oil of a consistent quality was not possible until base oil was refined. This process was developed around 1880. Technological advancements have shown that the quality of the operating fluids produced in the refinery was still not sufficient and that they had to be supplemented by additives to improve the quality (from approx. 1910). Researching these supplements (additives) is still of a high priority today.

The safe and reliable operation of stationary equipment, such as transfer lines, machining centres, presses and paper machinery, or heavy industrial and mobile equipment, such as excavators, wheel loaders and bulldozers, is possible only through the use of operating fluids which are adapted to the respective application.
These are therefore used widely in industry. The main task is the transmission of pressure from the pump to the consumer.

Without these operating fluids, systems and machines would not function as the friction between the friction partners is high and would lead to rapid destruction of the respective components.
In this way the operating fluid has a decisive influence on the reliability and longevity of machines and systems. This means that any knowledge about the operating fluid, the correct selection of operating fluids and their handling and application is of major importance.

Operating fluids comprise of an extremely wide spectrum of very different products and qualities. They are often purchased or selected for systems based on given specifications such as API, ACEA, MIL, DIN or the approvals issued by the manufacturer. This is perhaps the easier way, but it does not take into account the economic and ecological viewpoints. This is because specifications and standards only describe the minimum requirements on a lubricant and therefore make no statements on for example their quality reserves of their range of applications. We must also remember that there is no lubricant which completely and ideally covers all technical, health and environmental viewpoints. When selecting the most suitable lubricant, therefore, the entire environment of the lubrication must be taken into account, such as the transport, storage, handling, application, toxicology and disposal. Contradictory requirements must be carefully set against each other and balanced.

The maintenance of the value of a machine starts with the selection of the correct lubricant. Lubricant must be able to guarantee correct function even in the most adverse of conditions. In order to fulfil all lubricant specifications, a number of different products are required. These can be fully synthetic or based on mineral products.

Unfortunately, this vital element "operating fluid" is generally neglected during the design of a machine or system, and the development objectives:

- High reliability of the entire unit
- Long component life expectancy
- High degree of efficiency on the overall system through reduction of the energy costs
- Largest possible environment protection
- Low maintenance costs due to long intervals between replacements
- Low noise emissions

are therefore only achieved to a certain extent.

The condition, characteristics and care of the operating fluids play an important role in fulfilling the expected life expectancy and the degree of efficiency of the components and the entire system.

Increased requirements placed on the system, such as:

- Reduced or no leakage
- Compact design of the overall system and individual components
- Increased power density
- Reduced tank content
- Longer maintenance intervals

consistently increase the quality requirements on the operating fluid used.

Depending on the application case in the devices, the operating fluids must fulfil important functions.

The rapid development of machines and systems forces manufacturers of operating fluids to revise their product ranges or to supplement them with new products.

Rising temperatures and pressures, higher performance densities, smaller filling quantities and the resulting high circulation indexes are only some of the consistently increasing loads on lubrication. This means that the purchase of a "cheap" lubricant which, for example, just about fulfils the DIN, API or ACEA requirements, might in fact prove to have been an expensive decision. High amounts of wear, frequent operating malfunctions and failures, substantial effort for repairs and spare parts, short usage periods for oil fillings and high disposal costs may result. In addition, the economic balance of a company will hardly be negatively affected through the procurement of a high quality lubricant. Experience has shown that lubricant costs total less than 1 % of all operating costs which can be influenced, whereas for example repairs, maintenance and care costs total almost 50 %.

Only problem-free operation of high-performance systems and machines justifies their high investment costs, and a lubricant with substantial quality reserves is one of the prerequisites for it.

Depending on the application case in the devices, the operating fluids must fulfil important functions.

These are, for the most part:

- Pressure transmission
- Lubrication of components to reduce friction and wear
- Reliable formation of the lubricating film even under high pressures
- Cooling of components such as for example valves, pumps and bearings
- Support of seals in their sealing function
- Absorb moisture and neutralise existing acids to protect components from corrosion
- Keeping solid particle contamination suspended and transporting it to the filter

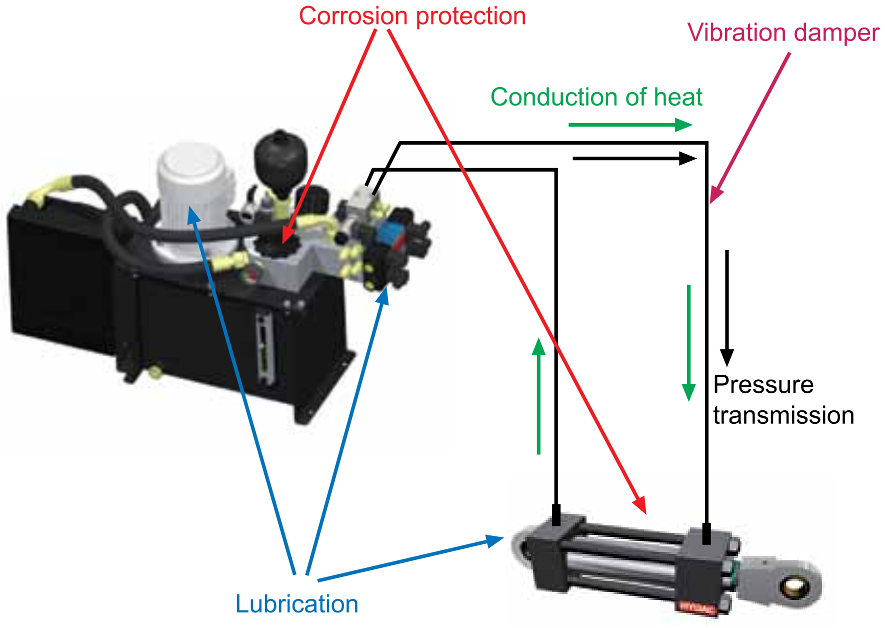


Fig. 1 Operating fluid as an element of design

As already mentioned, operating fluids are a very important machine element.

So that the reliability and the life expectancy of the components is guaranteed, the system manufacturer must choose:

- The proper type of lubricant
- A suitable lubrication procedure
- A suitable viscosity class for sufficient lubrication film formation

for each component.

Furthermore, it must be ensured that operating fluid is available:

- In sufficient quantity and pressure
- With a low degree of contamination

for the lubrication and/or the hydraulic circuit.

To fulfil these tasks, operating fluids must meet certain requirements:

- Defined flow properties, meaning optimal viscosity-temperature characteristics
- Deployable over a wide range of temperatures
- Shear stable
- Largely resistant to ageing
- Friction and wear reducing
- High degree of protection against corrosion
- Good air release capacity
- Low degree of foaming
- Seal material compatibility
- Physiologically harmless
- Resistant to deposit formation
- Largely incompressible
- Not readily flammable
- Rapidly biodegradable
- Good filterability properties
- Good contaminant release properties
- Good electrical conductivity
- Good thermal conductivity

Different operating fluids are used to realise these requirements:

- Mineral oils
- Rapidly biodegradable oils
- Synthetically produced oils
- Flame-retardant fluids
- Phosphate ester
- Water

The continually rising level of demand and the requirements that operating fluids are subject to have resulted in the development of high-tech products based on one or more mineral, synthetic or semi-synthetic base oils, such as esters or glycols, that are adapted to the desired characteristics through the addition of additives.

The most commonly used additives are:

- Antioxidants – improved resistance to ageing
- Corrosion inhibitors – protection against corrosion
- Anti-wear additives – reduction of wear
- Anti-foaming additives – curb the tendency to foam
- VI improvers – improve the viscosity-temperature characteristics
- Pour point depressants – ensure fluid flow even at lower temperatures
- Special applications require additives with detergent and dispersant properties.

1.2 Particular requirements made of operating fluids

1.2.1 In hydraulic systems

In hydraulic systems, the primary function of the operating fluid is the transfer of pressure. At the same time, it has the task of providing the pressure generated by the pump to every point in the system.

This is based on Pascal's principle, as stipulated already in the 17th century:

"Any change in pressure exerted at any point in a chamber in a static, incompressible fluid which does not disturb the equilibrium of the fluid is transferred equally to all other points throughout the fluid. Assuming the pressure forces are greater than the mass forces, then the static pressure in the fluid will act equally at all points."

The static pressure always acts at right angles to the container's boundary surfaces. Using the static pressure of a fluid, it is thus possible to transmit forces and power.

$$\frac{F_1}{F_2} = \frac{A_1}{A_2} = \frac{s_2}{s_1} \qquad p = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

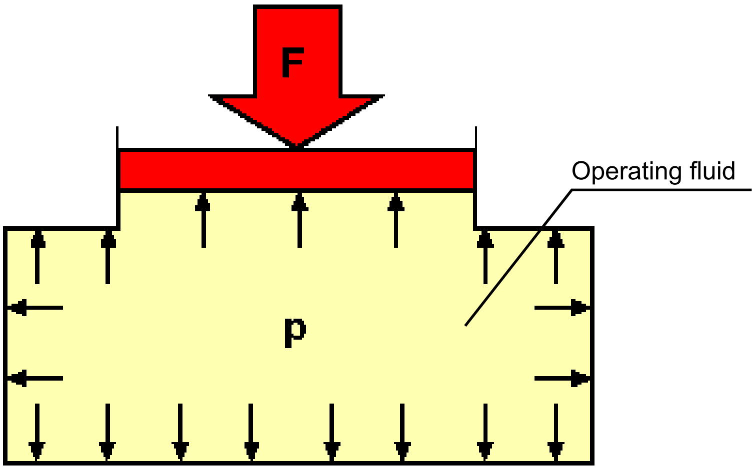


Fig. 2 Hydrostatic principle according to Pascal (source: Mr Bock, Hydraulic fluids as an element of design)

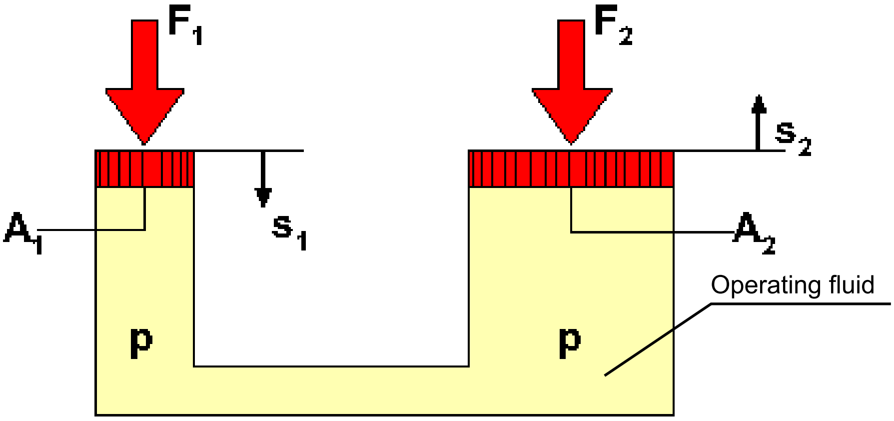


Fig. 3 The principle of a hydraulic press (source: Mr Bock, Hydraulic fluids as an element of design)

In a hydraulic system, fluid is pumped through lines by means of a pump, with a piston at the end being moved by the hydraulic fluid. A comparatively small amount of pumping power is required to transmit a large amount of force due to the principle of the lever, or leverage. This is demonstrated in the following illustration.

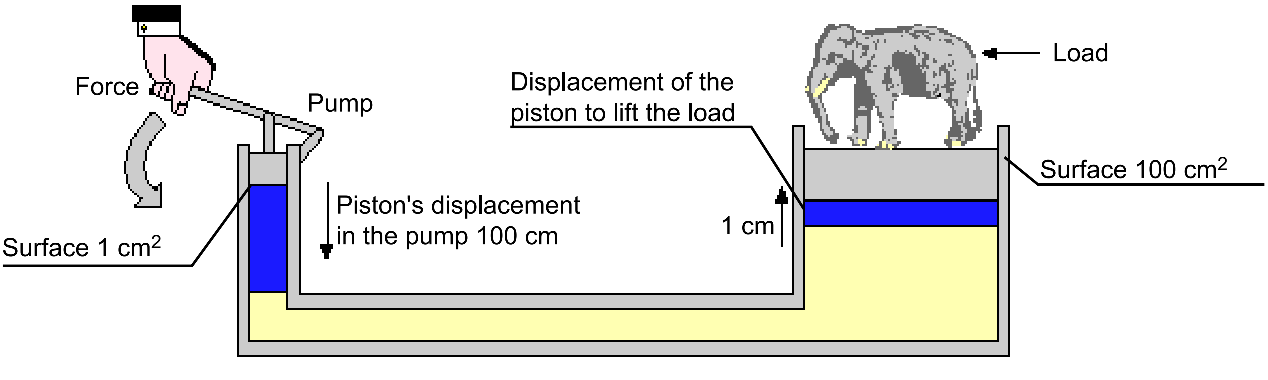


Fig. 4 Basic principle of a hydraulic system (source: VSI)

What appears at first glance to be a very simple product, reveals itself upon closer inspection to be quite an elaborate one. This, of course, is because hydraulic systems are not constructed as simply as the illustration implies but, as such, pose special requirements on the hydraulic fluids used. The following illustration depicts the elements in a typical hydraulic system. The demands placed on the fluid by the individual elements are listed next to each element.

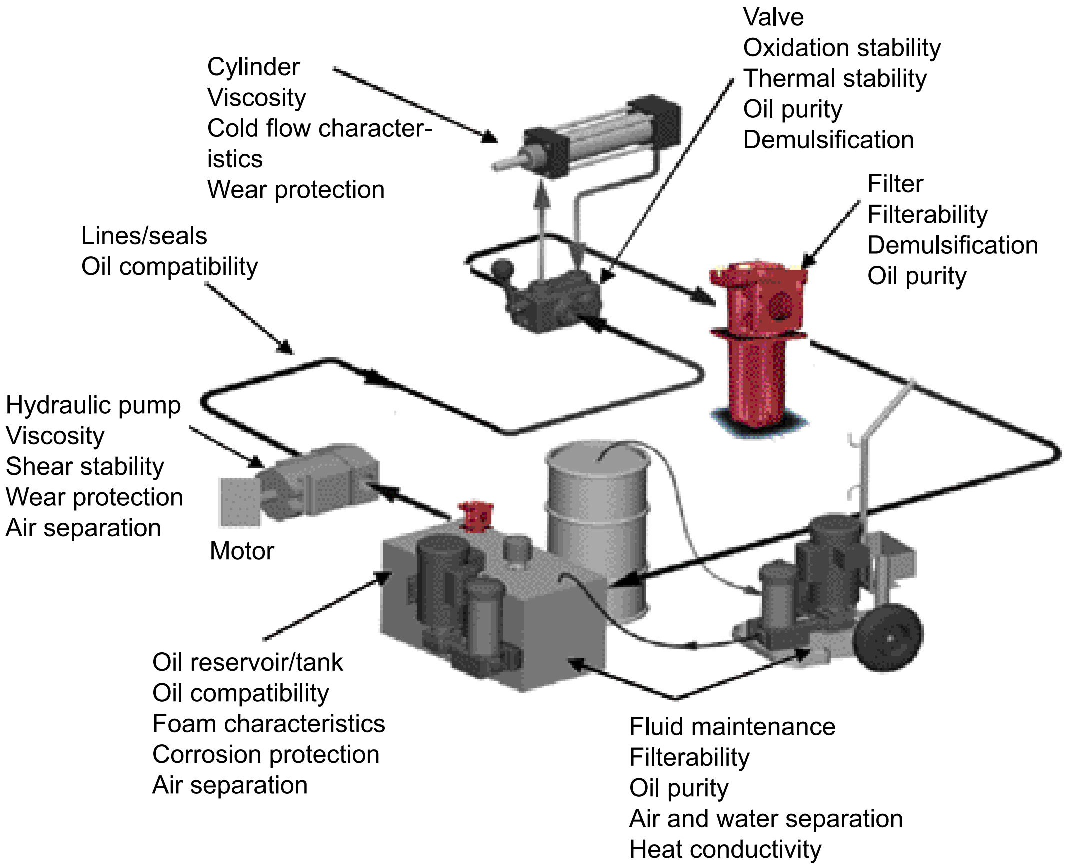


Fig. 5 Requirements on the hydraulic fluid

In order for the hydraulic fluid to meet these requirements, the following properties and flow processes must be considered more closely:

- **Fluid properties:**
  - Density
  - Viscosity (thickness)
  - Elasticity (compressibility and modulus of elasticity)
  - Specific heat capacity
  - Surface tension (capillary action)
  - Solubility of gases, air and water
- **Hydrostatics:**
  - Pressure
  - Buoyancy
- **Theoretical description of the flow processes:**
  - Consideration as kinematic or dynamic
  - Continuity condition, conservation of mass
  - Linear momentum
  - Equation of motion (Euler's equation of motion)
  - Energy equations and simple formulas related to the flow calculation (Bernoulli's energy equation)
  - Hagen–Poiseuille law
  - Laminar flow
  - Turbulent flow
  - Hydromechanically dimensionless numbers: Froude number, Reynolds number, Euler number
- **Real flows:**
  - Flows within pipelines and tanks
  - Flows within valves and bearings
  - Flows within pumps and cylinders

1.2.2 In lubrication systems

With regard to the lubrication of components, such as shaft bearings, pumps (cylinder liners), tracks, etc., the primary task of the operating fluid is to reduce friction.
In addition, it is essential that the lubricant forms a sufficient lubricating film thickness that prevents contact between the sliding surfaces.

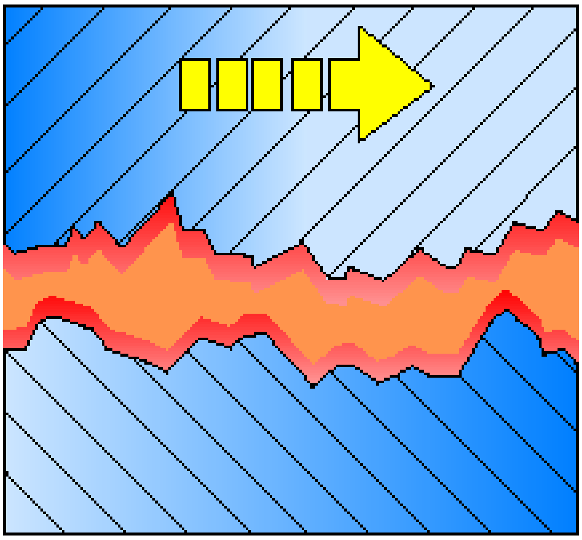


Fig. 6 Fluid friction: both bodies are completely separated from each other by the fluid layer, meaning that the bodies are literally swimming on a layer of lubricant. There is practically no wear. (source: BP)

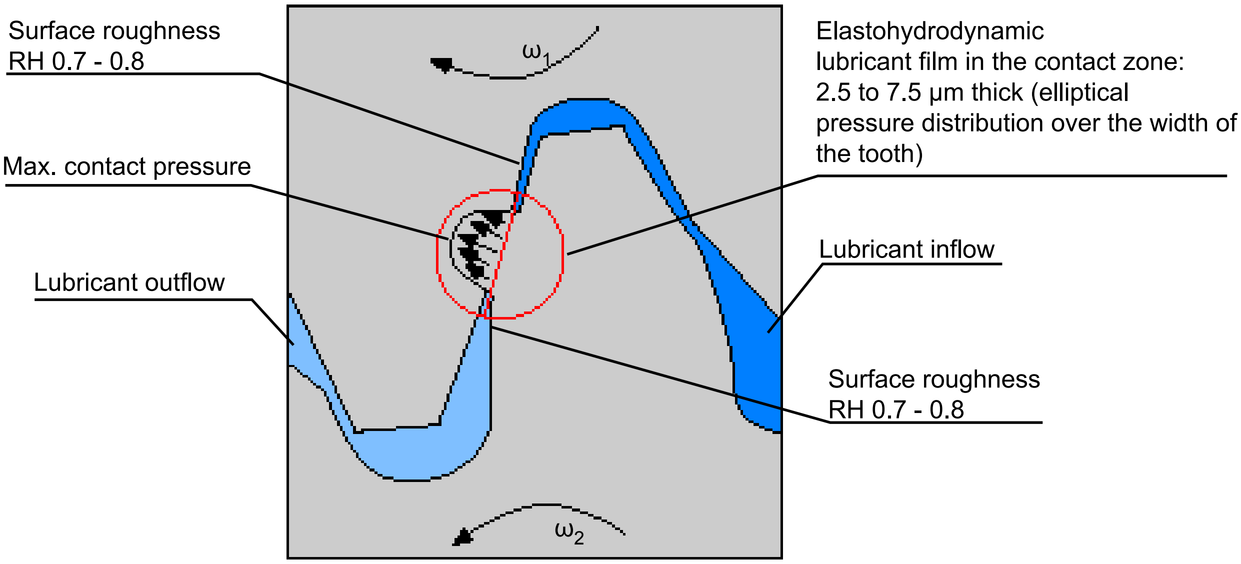


Fig. 7 Lubrication of a spur gear: the lubricating film serves to transmit the force between the driving gearwheel and the gearwheel being driven.

The actual lubrication is distinguished between the following lubrication processes:

Boundary lubrication:

In this process, the lubricant permeates the solid body and forms a reaction layer, which does not cover the asperity contact area of the solid body. The load is transferred to the friction partner via the asperity contact area. The component life expectancy is thereby severely limited. For this reason, the lubricant must be developed in such a manner that this condition does not occur.

Semi-fluid lubrication:

The load is transferred in part by the lubricating film and in part by contact within the asperity contact area.

Fluid-film lubrication:

The load is taken up completely by the lubricant. The contact surfaces are separated. Fluid-film lubrication can be further subdivided into:

- Hydrostatic lubrication
- Hydrodynamic lubrication
- Elastohydrodynamic lubrication

Hydrostatic lubrication:

Separation of the contact surfaces takes place by pumping the lubricant into the lubrication gap. From the technical perspective, this form of lubrication is very complicated, and from the design perspective it is very challenging.

Hydrodynamic lubrication:

The lubricant is conveyed to the narrowing lubrication gap through the movement of the contact surfaces relative to each other. The lubricant pressure is so high that the contact surfaces are lifted apart from each other.

Elastohydrodynamic lubrication (EHD):

This form of lubrication is common with highly stressed, moving roller bodies such as gearwheels and roller bearings. In addition to the basic hydrodynamic equations, elastohydrodynamic theory also considers the elastic deformation of the bodies in contact. Characteristic for this type of lubrication is a narrowing of the lubrication gap at the end of the contact zone. EHD theory provides the basis for calculating the effect of the lubrication on gearwheel damage such as pitting, scuffing or grey staining.

Depending on the arrangement of the lubricating points and how these points are supplied, a distinction is drawn between:

Total-loss lubrication:

Total-loss lubrication designates exclusively the supply of lubricant to the lubrication points. Supply can take place manually, semi-automatically or automatically. Following usage, the lubricant is forced out of the lubrication gap provided it is still present.

Circulating lubrication:

Circulating lubrication describes a lubricant dispensing circuit. The circuit comprises a reservoir, such as an oil pan, supply to the friction point and the return line. It is recommended to interconnect a lubricant reconditioning element, such as an oil filter, in the line.
Circulating lubrication requires less lubricant due to its reuse. The lubricant is not able to escape into the environment because of the closed system.

Lifetime lubrication:

Lifetime lubrication can be understood as a one-time provision of lubricant to a friction point, which will not be renewed or replaced to the end of its service life.
This is commonly used in roller bearings, but also finds application in linear guiding systems, for example. These systems are usually provided with a lubricant grease packing (lubricating oil film with special thickeners) that is retained in the bearing or guiding system through sealing rings.

Individual lubrication:

An individual lubrication is used when only one lubrication point is present, when a central lubrication system is to be used or when the lubrication point cannot be reached by the central lubrication system.

Manual individual lubrication:

Manual individual lubrication is always a total-loss lubrication.

Central lubrication:

Central lubrication systems should be considered when multiple lubrication points need to be serviced. One advantage exists in the reduction in overall maintenance efforts. Both wear and lubricant consumption are reduced because of the regular lubrication at the proper dosing.

In order to meet the requirements:

- Reduction of friction and thus of wear
- Transmission of force
- Cooling
- Damping of vibrations
- Sealing effect
- Corrosion protection

the lubricant must be matched to

- Pressure and shearing stress at the lubrication point
- Heat build-up and dissipation
- Any chemical interaction with substances from the friction partner or seals, or from the surrounding area
- Lubricant ageing

influences.

From this, the most important physical characteristic values for lubricants are derived:

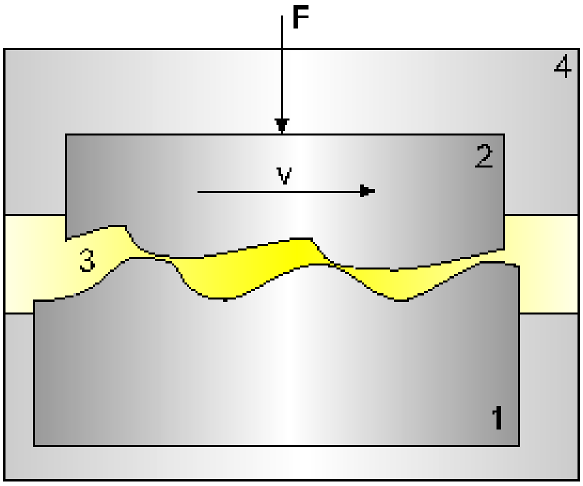
- Density
- Viscosity
- Dropping point
- Point of solidification, pour point
- Flash point, combustion point, inflammation point

2 Operating fluids – an important element in tribological systems

2.1 General

Tribology is the science and engineering of surfaces in contact and interacting in opposing relative motion, as well as their corresponding processes.
It considers the scientific description of friction, wear and lubrication, as well as the development of technologies for the optimisation of friction processes. Its objective is the optimal design of lubrication and hydraulic system components in order to ensure damage-free operation of the overall system to the greatest extent possible.

A tribological system is comprised of two material surfaces whose fiction is reduced through the use of a lubricant, as well as their surrounding area.



1: Primary body (material 1)
2: Counter body (material 2)
3: Media in between, e.g. lubricant
4: Environment

Fig. 8 Tribological system – two materials, lubricant and its environment

The basic tasks of a tribological system are to:

- Separate the primary and counter bodies through a suitable operating fluid matched to the application concerned
- Provide good lubrication between the bodies through sufficient operating fluid load-bearing capacity
- Prevent wearing of the bodies (low material loss)
- Minimise friction between the bodies (low energy requirement)
- Prevent corrosion

2.2 Friction

Friction is a physical process which can also possess positive properties for many devices. For example, without friction, a screw could not be securely tightened. Friction is generated by the relative motion of the primary body to the counter body. This causes dissipation, which means that friction retards the relative motion between the primary body and the counter body.

In most lubrication and hydraulic applications, the following friction conditions emerge:

Dry friction (also known as stiction):

Dry friction results from the contact of two surfaces sliding over one another. In the process, the surface elevations are levelled (abrasion or wear). With adverse material pairing or high surface pressure intensities, surface fusing takes place (adhesion). Solid body friction, for example, occurs when a lubricant is not used or the lubrication process has failed. This type of friction is typically present in standing systems whose separating oil film has been pressed away. When the system (e.g. a turbine) is restarted with a missing oil film, a high degree of wear and permanent damage to the components results.

Possible remedies:

- Artificial development of a sufficient oil film prior to startup by means of an ancillary unit
- High oil viscosity or the addition of suitable additives

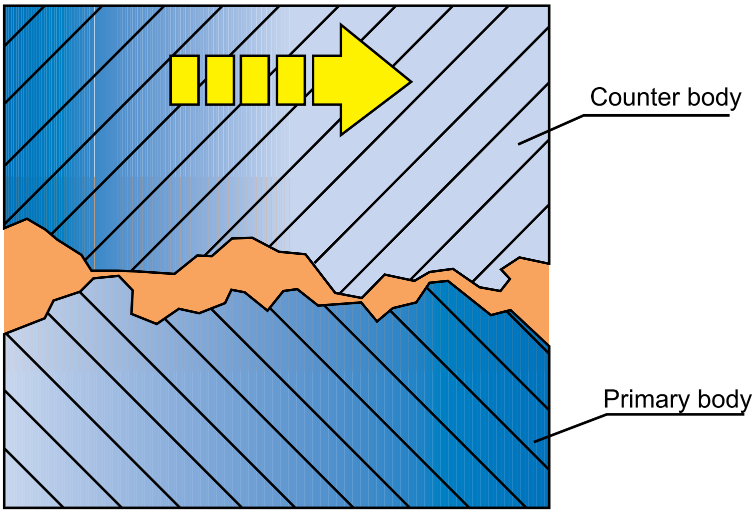


Fig. 9 Dry friction (source: BP)

Mixed friction:

Mixed friction can occur due to insufficient lubrication or during the initial motion of two lubricated friction partners, such as during system startup. Pointed contact thereby occurs at the peaks of the sliding surfaces. The frictional force is less than with solid body or fluid friction. The wear, however, is higher than with pure fluid friction. For this reason, it is always an undesirable, yet sometimes unavoidable condition for continuous operations, but prevention efforts may be so complicated that the costs of wear-related repairs are considered acceptable.

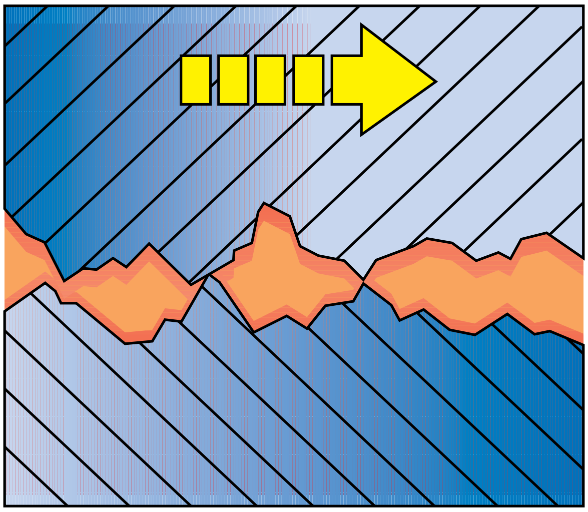


Fig. 10 Mixed friction (source: BP)

Stick-slip effect:

Stick-slip (in the context of sticking and slipping) refers to the "chattering" of solid bodies as they move against one another. It designates the rapid jerking motion of two slightly coupled surfaces alternatively sticking, bracing, separating and sliding against one another. Depending on the tribological system, this can result in oscillatory excitation that radiates as noise from resonating surfaces. The effect diminishes for the most part as soon as the friction partners are separated by an intermediary or a lubricant.

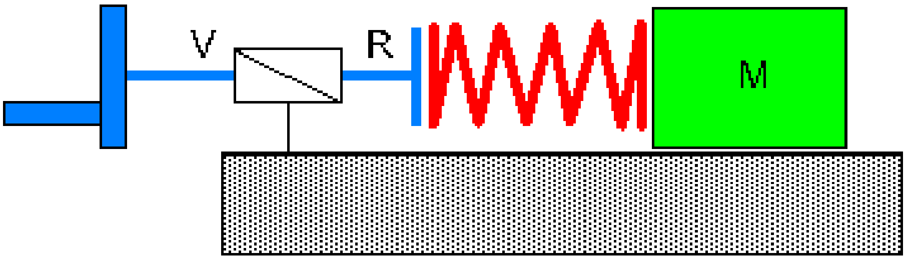


Fig. 11 Schematic representation of the stick-slip effect

Effects:

The stick-slip effect is usually undesirable. The negative effects of stick-slip effect can be seen in bearings and linear motion technology guide systems, as well as in other components or machine elements.

Pitting:

Pitting is a term that designates a type of damage on the primary and counter bodies. It is also defined as blistering and near-surface microcracking with respect to tribological loads. This occurs in roller bearings and gearwheels, for example. Pit formation with respect to tribological requirements is brought about by a local transgression of the respective material's solidity due to Hertzian stressing between the roller body and the inner or outer ring of the roller bearing, or the tooth flanks of the gearwheel. Decisive is the fact that, with Hertzian surface stressing, the maximum component stress does not occur at the component surface but at a characteristic depth beneath the surface.
Other influencing variables, besides Hertzian stressing, are surface hardness and hardness penetration depth, surface quality, flank form defects and circumferential speed (with gearwheels), oil viscosity, temperature and similar factors.

Fluid friction:

Fluid friction occurs when a permanent lubricating film has formed between the sliding surfaces. The sliding surfaces are completely separated from one another. The ensuing friction is based on the lubricant molecules sliding over one another. To ensure that these shearing forces result only in an acceptable lubricant temperature increase, the heat generated must be dissipated by suitable means via the lubrication gap.
Fluid friction is the desired condition in bearings and guide systems when endurance strength, high gliding speeds and heavy loading are needed.
The transition from mixed friction to fluid friction is depicted in the Stribeck curve. Fluid friction in a laminar flow is proportional to the velocity v, while in a turbulent flow it is proportional to the square of the velocity (v^2).

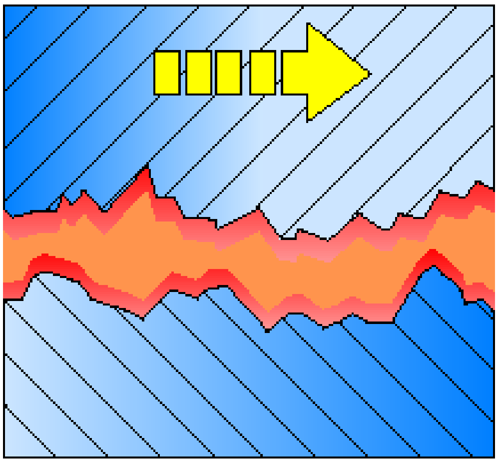


Fig. 12 Fluid friction (source: BP)

Internal friction:

Internal friction consumes energy through the motion of a material's atoms or molecules against one another, such as in flows within an oil. External forces such as gravity can effect each liquid particle while pressure differences can evoke accelerations. Internal friction is what makes materials ductile and fluids viscous. For every liquid particle, the external forces, the pressure forces, the friction forces and the inertia forces must remain in balance if the tribological system should not be accelerated.

Stribeck curve:

The Stribeck curve describes the progression of frictional force with relation to friction velocity in the case of hydrodynamic friction. It is named after the researcher, Richard Stribeck, who concerned himself with material hardness and the shaft bearing, among other problems.

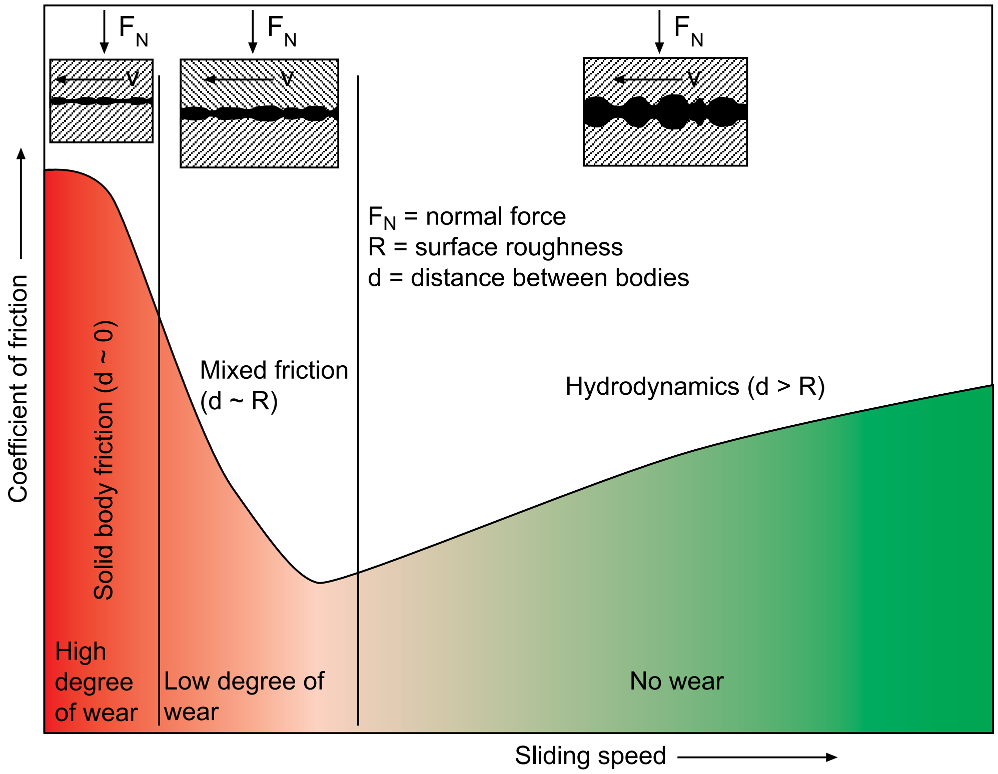


Fig. 13 Stribeck curve (source: Dr. Tillwich GmbH)

If no relative motion takes place, then static friction predominates. As soon as a force imposes itself that is larger than the static friction, relative motion will begin. At first, only a few molecules of lubricant separate the primary body from the counter body and boundary friction predominates. As soon as a thin film of lubricant forms, and with only a few asperities on the primary and counter bodies still sliding over one another without separation by the lubricant, then mixed friction is present. The transition from mixed friction to fluid friction (hydrodynamic or elastohydrodynamic friction), where the primary and counter bodies are completely separated by lubricant, is designated as the release point.

As continually more layers of lubricant are sliding over one another with increasing velocity, the friction forces in the fluid friction range begin rising once again. As a rule, wear is at a minimum within the fluid friction range.

2.3 Wear

Wear (abrasion) is the loss of mass of a material surface (surface abrasion) due to grinding, rolling, impacting, scratching, chemical or thermal stress.
These, for the most part undesirable, alterations of the surface occur, for example, in bearings, couplings, gears, nozzles and brakes. Wear is one of the main reasons for component damage and the corresponding failure of machinery and equipment. For this reason, the reduction of wear plays an essential role towards increasing the life expectancies of machinery and equipment and, correspondingly, saving costs and reducing raw material consumption.

Definition according to DIN 50320 (standard retracted in 1997):

Wear is the progressive loss of material from the surface of a solid body (primary body), brought about by mechanical causes, referring to the contact and relative motion of a solid, liquid or gaseous counter body.

Variables having an effect on wear:

- Primary body (material, form, surface)
- Intermediary (type, particle size, and the like)
- Counter body (material, form, surface)
- Load (size, progression over time)
- Type of motion (sliding, rolling, impacting)
- Surrounding atmosphere (e.g. air, protective gas, vacuum)
- Temperature (degree, progression over time)

Wear is always a property of the system, not a property of the components involved.

2.3.1 The mechanisms of wear

Wear is determined primarily by four different wear mechanisms:

Adhesive wear:

If two contacting components are pressed firmly together, the contact surfaces adhere to one another due to adhesion. Particles will be sheared off when gliding. Holes and scale-like material particles ensue that often remain on the sliding surface of the harder partner. This wear mechanism is called adhesive wear. Adhesive wear occurs with insufficient lubrication.
Adhesive wear arises when components slide against one another without an intermediary or when the intermediary is displaced due to the high surface pressure intensity. Surface layer particles are sheared off due to adhesive friction.

Abrasive wear:

When hard particles in a lubricant or asperity contact area penetrate the boundary layer of the friction partner, scoring and micro-chipping results. This type of wear is designated as abrasive wear.
In order to prevent abrasive wear, lubricants should be monitored and renewed as necessary. Fundamentally, measures can be taken even during the design stage of a tribological system to prevent abrasive wear. Instead of metal-metal pairing, metal-synthetic or metal-ceramic pairing should be preferred. As a rule, a favourable relationship between hardness and ductility should be pursued with metal pairing, such as the use of hard carbide in a ductile intermediary.
Abrasive wear plays a particular role in systems in which media are conveyed that contains hard, sharp-edged particles. Abrasive wear is prevalent in pipelines and pumps, for example, through which water with suspended matter (sand), plaster and cement (aggregates) or synthetic filled compositions (filler) are to be conveyed, such as with casting systems. In these cases, abrasive wear is significantly responsible for shortening the life expectancies of the through-flow components.
Abrasive wear can be determined by a mechanical testing procedure, via the so-called Taber Abraser, according to ISO 9352, ASTM D 1044 or DIN EN standard 438 - 2.6. In this test, wheels fitted with sand paper are pressed at a defined pressure against the rotating surface of the test specimen. The measured variable usually relates to the loss of mass of the test specimen after a specific number of revolutions. Abrasive wear is a chipping in the micro-range.

Surface fatigue:

Surface fatigue is a mechanism of wear that is brought about by repeated alternating mechanical stresses. A breakdown of the surface results, leading to the formation and propagation of cracks in the layers of material close to the surface. Surface fatigue is prevalent in roller bearings, for example, due to the continuous rolling contact stress. This type of wear, also referred to as roller wear, causes the formation of pits, or pitting. As tensile stresses in the surface promote surface fatigue, compressive stresses can be introduced into the surface as a counter measure. Suitable processes for this include nitration, oxidation or ball-peening of the surfaces.

Tribo-oxidation:

The formation of intermediary layers, such as oxide layers, resulting from chemical reactions and their destruction due to component motion is referred to as tribo-oxidation or reaction layer wear. This almost always occurs together with adhesive wear. This wear mechanism, occurring as a result of chemical reaction and mechanical destruction in the reaction layer, is a tribo-chemical reaction. One example of tribo-oxidation is fretting corrosion.

2.4 Function of the operating fluid

General:

Pressure media are energy savers in that they reduce friction and material savers in that they reduce component wear. In addition to these primary tasks, they take on many more tasks related to the machine or its surroundings (installation site).

These include, among other tasks:

- Tribo-system cooling
- Lubrication of cylinder and pump seals
- Protection of components against corrosion

Lubricating film thickness:

The life expectancies of the components in lubrication and hydraulic units will be affected by the lubricating film present.

The required lubricating film thickness will be affected by:

- The properties of the operating fluid
- The operating conditions
- The geometry of the contact surfaces.

Above all, operating fluid viscosity throughout the operating temperature range will have a dominant effect on the required gap width between the moving bodies and the oil film thickness. This means that in a colder environment with a correspondingly high viscosity the machine will exhibit greater energy consumption at the system drives, while at higher operating temperatures with a correspondingly low viscosity the oil film will separate and result in serious damage to the components.

Tribological characteristics:

The addition of additives to the base oil has the primary function of improving the tribological characteristics of the operating fluid selected.

Tasks of the pressure media:

- To separate sliding partners (moving bodies)
- To seal lubrication points
- To remove energy fed into the system and transfer it to the cooling system
- To protect components

3 Composition and production of operating fluids

3.1 General

Operating fluids are mainly produced from crude oil, also known as raw oil. This crude oil, emerging out of prehistoric times from the remains of dead, single-celled microorganisms cut off from oxygen and exposed to extreme pressure and heat, must be brought up by high-quality conveyor systems from deposits (e.g. porous sandstone) lying many thousands of feet below the surface.

Even with the most modern conveyor systems, a maximum of only 50 % of the crude oil stored in these stone reservoirs is recoverable. The quality of the crude oil extracted is heavily dependent on the location and the region. The typical oil producing regions are depicted in the following table.

Region Trade name	Libya Zueitina	Great Britain Forties	Middle East Agha Jari	Middle East Arabian Heavy	Middle East Safaniya
Gases Petrol	1% 22%	3% 19%	2% 20%	2% 15%	2% 13%
Middle distillates (e.g. heating oil EL)	39%	37%	30%	26%	25%
Residue	38%	41%	48%	57%	60%
Density g/ml	0.817	0.840	0.855	0.887	0.890
Sulphur wt%	0.21	0.30	1.40	3.00	2.80
Price			Ascending		
Typical features	Rich in naphthenes	Low sulphur content		High sulphur content	High sulphur content

Tab. 1 Typical producing regions and qualities of extracted crude oil (source: VSI)

Basically, crude oil is made up of multiple chemical compounds and molecules.

The most important are:

- Carbon (C)
- Hydrogen (H)
- Sulphur compounds
- Nitrogen compounds
- Oxygen
- Various trace elements

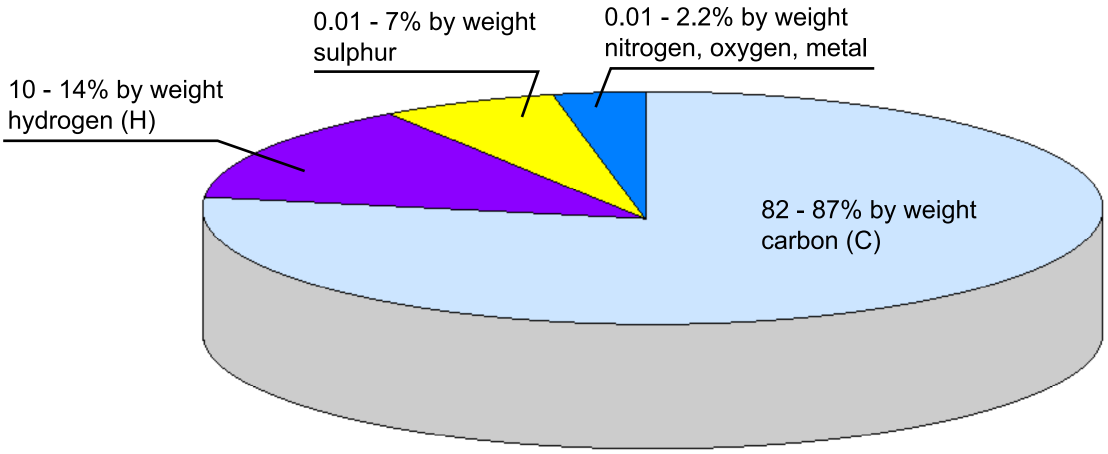


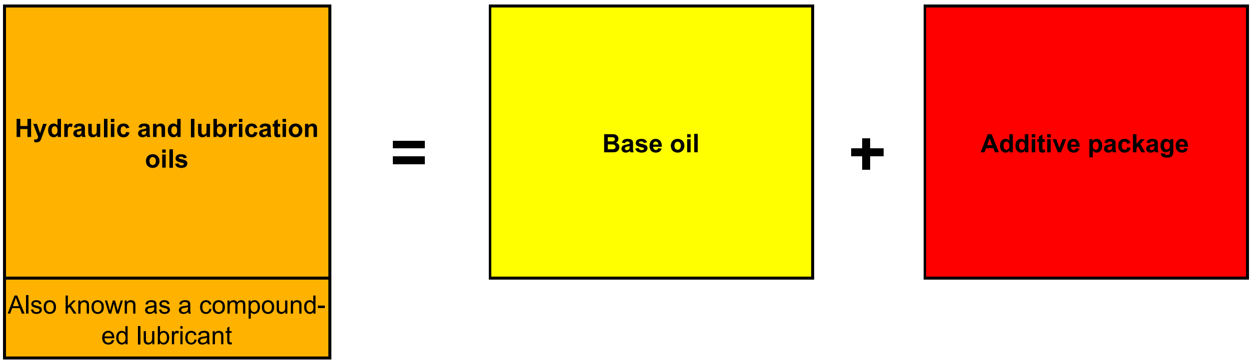
Fig. 14 Composition of crude oil (source: VSI)

The main proportion of base oils used today is comprised of hydrocarbons derived directly from crude oil. This is primarily for economic reasons. Base oil fractions are derived from the crude oil by means of various physical (distillation, extraction) and chemical (hydrogenation) processes. For the most part, these fractions are composed of saturated hydrocarbons (paraffins) from straight-chain (n-paraffins), double-chain (isoparaffins) or cyclic structures (naphthenes).

The base oils for lubricating and hydraulic fluids are:

- Raffinates
- Hydro-crack oils
- Synthetic oils (polyalphaolefins, polyglycols, esters)
- Vegetable oils

Base oils in their natural form can no longer fulfil the continuously increasing level of demand placed on lubricating and hydraulic oils. Through the addition of active chemical substances, additives, the properties of operating fluids can be specifically altered so that, today, virtually every such fluid or grease contains a so-called additive package comprised of a combination of carefully tested active substances.



In general, the following applies:

The base oils for lubricating and hydraulic oil are responsible for the ability of the lubricating film to bear a load. The additive package used has the main task of protecting the surface of the components or the effective area.

3.2 The structure of molecular chains

The structure and number of carbon and hydrogen atoms in molecular chains determine the resulting basic products for the production of lubrication and hydraulic fluids.

Possible structure of the hydrocarbon molecule:

The hydrogen atom is monovalent (i.e. it has a valence of one). This means that the hydrogen atom can only bind one single atom to itself. The carbon atom is tetravalent, meaning that it can bind four atoms to itself. It forms the framework for the hydrocarbon molecule.

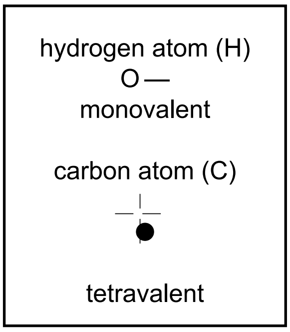


Fig. 15 Valency of the C and H atoms

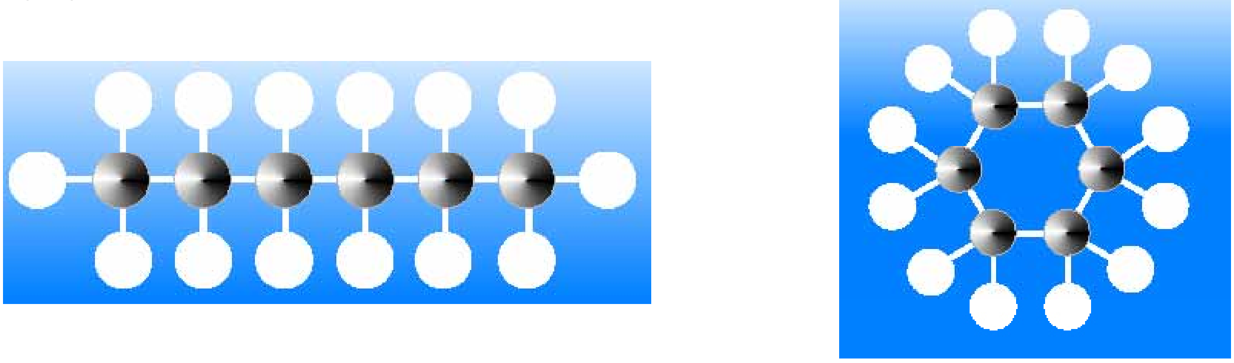
Formula:

C_nH_{2n+2}

Hydrocarbon molecules can string themselves together in a:

- Chain-like (acyclical) or
- Ring-like (cyclical)

manner.



Chain-like compound

Ring-like (cyclical) compound

Fig. 16 Framework of the hydrocarbon molecules (saturated) (source: BP)

Single or multiple bonds can ensue when the hydrogen atoms are linked to the carbon atoms.

With a single bond, also designated as saturated, an inert hydrocarbon compound forms. These compounds feature a high degree of ageing stability and thus make possible long intervals between oil changes without serious change to the oil.

The compounds with one or more double bonds, also referred to a unsaturated hydrocarbons, are reactive. These split apart with the introduction of oxygen. The formation of ageing products results.

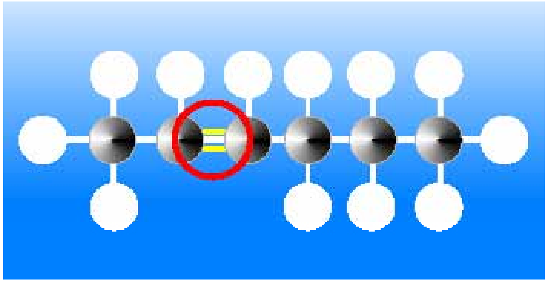


Fig. 17 Unsaturated triple compound (Source: BP)

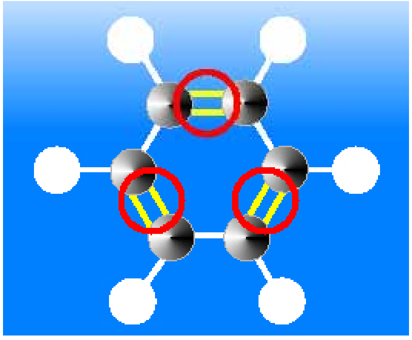


Fig. 18 Unsaturated double compound (source: BP)

Molecular structures:

The various binding forms of the C atoms in hydrocarbons are summarised in molecular structure groups. The designation of these structures is listed in the following table.

Nomenclature for molecular structures	
Acc. to IUPAC*	Commonly called
Alkanes	Paraffins
Normal alkanes	Normal paraffins
Isoalkanes	Isoparaffins
Cycloalkanes	Naphthenes (cycloparaffins)
Alkenes	Olefins
Alkadienes	Diolefins
Alkynes	Acetylenes
Aromatic compounds	Aromatic compounds

* International Union of Pure and Applied Chemistry

Tab. 2 Molecular structures

Alkanes (paraffins):

In alkane molecules, the carbon atoms are only linked through a standard single bond; all free bonds are saturated with hydrogen atoms – their molecules therefore contain no functional groups and they thus belong to the most inert organic compounds.
These are saturated hydrocarbons and are thus inert.

Formula:

C_nH_{2n+2}

Paraffins are further differentiated into:

- Normal paraffins with C atoms in a row
- Isoparaffins with C atoms in a row with branches

This group includes:

- Methane (CH_4) – gaseous, principle constituent of natural gas
- Ethane (C_2H_6) – gaseous
- Propane (C_3H_6) – gaseous, liquid state with slight pressure
- Butane (C_6H_{14}) – gaseous, liquid state with slight pressure
- Pentane
- Hexane
- Heptane
- Octane

} liquid

Paraffins are solid from 17 C atoms onwards.

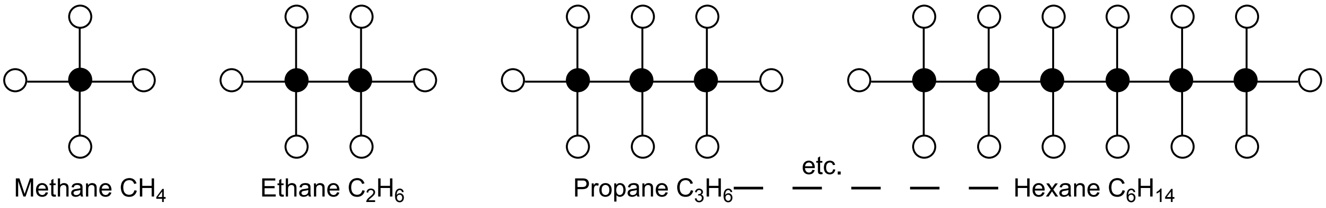
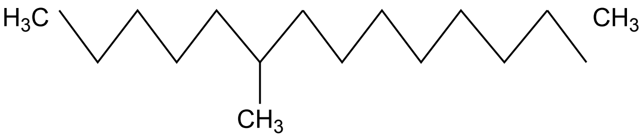


Fig. 19 Structure of the individual paraffin (alkane) groups
Saturated hydrocarbons with straight (normal paraffin) and branched (isoparaffin) chains (source: BP)

Simplified skeletal formula:



Properties:

- High pour point
- Poor temperature characteristics
- Viscosity index > 90

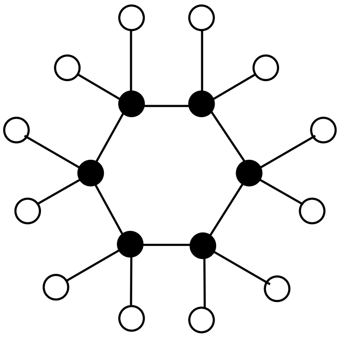


Fig. 20 Naphthenes (cycloalkanes)
Saturated hydrocarbons with rings of mostly five, six or seven carbon atoms (also referred to as cycloparaffins), distinguished by their low-temperature stability (source: BP) Formula: CnH2n

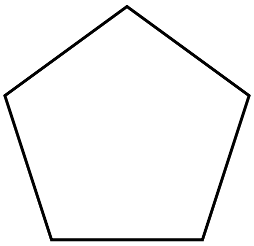


Fig. 21 Naphthenes (cycloalkanes)
Simplified skeletal formula

Properties:

- Good temperature characteristics
- Low viscosity index

Alkenes (double bonds):

These are unsaturated hydrocarbons. They usually occur with local overheating in distillation systems. They are distinguished from paraffins in that they are highly reactive. Olefins are not contained in crude oil. They are usually created during further processing, such as with the cracking process.

Double and triple bonds possess the ability to add on other atoms or atom groups (accumulation). Compounds with double and triple bonds behave like unsaturated ones and are less inert than alkanes.

Formula:

C_nH_{2n}

This group includes:

- Ethene (also called ethylene) – gaseous, mostly used in the production of plastics
- Propene
- Pentene
- Hexene

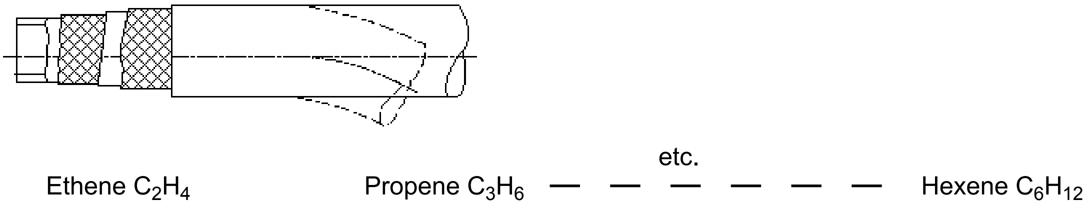


Fig. 22 Structure of the individual olefin groups
Unsaturated hydrocarbons, more reactive than paraffins and therefore a basic substance for further chemical processing (source: BP)

Alkynes (triple bonds):

Alkynes and alkenes are reactive compounds; unsaturated hydrocarbons.

Formula:

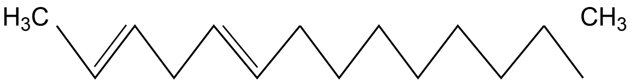
C_nH_{2n-2}

Organic acids:

Formula:

COOH

Simplified skeletal formula:

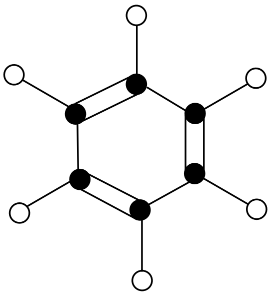


Aromatic compounds:

These are unsaturated hydrocarbons.

Formula:

C_nH_n or C_nH_{n-2}



Benzene C_6H_6

Fig. 23 Structure of the aromatic compound "benzene" C6H6 (source: BP)

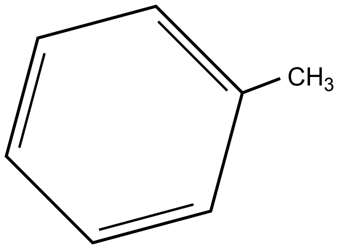
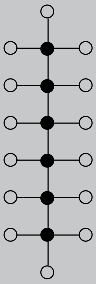
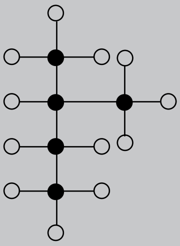
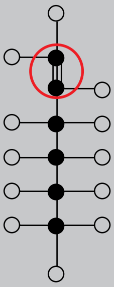
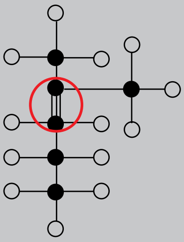
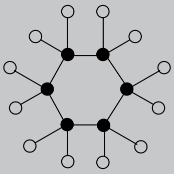
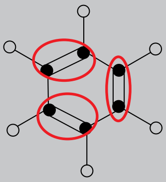


Fig. 24 Simplified skeletal formula:

The basic framework for the aromatic compounds is the particularly stabile benzene ring comprised of six carbon atoms with three double rings and three single rings. Aromatic compounds are temperature resistant, exhibit good knock resistance in motors and are a source material for the chemical industry. (source: Aral)

Properties:

- Very good solubility of additives
- Usually toxic (poisonous)
- Component in group I base oils (not contained in group II and group III base oils)

Group	Normal alkanes Normal (n)-paraffins	ISO-alkanes ISO (i)-paraffins	Alkenes Normal (n)-olefins	Alkadienes ISO (i)-olefins	Cyclo-alkanes Naphthenes	Aromatic compounds
Structure	Straight chain	Branched chain	Straight chain	Branched chain	Ring-shaped	Ring-shaped
Chemical character	Saturated	Saturated	Unsaturated	Unsaturated	Saturated	Unsaturated
Example	n-Hexane	i-Hexane	n-Hexane	i-Hexane	Cyclohexane	Benzene
O = H ● = C						
Manufacturing processes	Distillation catalyt. cracking		Catalyt. cracking		Distillation	Catalyt. cracking
Tendency to react	Inert		Highly reactive		Inert	Highly reactive
Energy content	High		Medium		Low	
Density	0.66	0.63	0.67		0.78	0.88
Ignitability	Good	Low	Low		Medium	Bad
Low-temperature characteristics	Bad	Good	Good		Good	Medium

Tab. 3 Summary of the composition and properties of the individual hydrocarbons (source: VW)

	Alkanes, paraffin-based	Alkenes, naphthene-based
Carbon in a paraffin bond	>60 %	<60 %
Density	Low	Higher
Viscosity-temperature characteristics	Good	Medium
Resistance to ageing	Good	Bad
Thermal resistance	Medium	Good
Flash point	high	Medium
Evaporation tendency	Low	Medium
Low-temperature characteristics	Bad	Good
Additive solubility	Medium	Good
Wettability	Medium	Good
Aromatic content	Low	Medium
Amount of polycyclical aromatics contained	Extremely low	Very low
Elastomer compatibility	Good	Good

Tab. 4 Comparison of paraffin/naphthene-based oils

Characteristic data of various hydrocarbons:

The size of the molecule chain determines the evaporation characteristics of the hydrocarbon. The smaller the carbon atoms, the lower the boiling temperature.

Hydrocarbon	Formula	Boiling point (liquid → gaseous)	Melting point (liquid → solid)
Methane	C_1H_4	-150 °C	-160 °C
Propane	C_3H_8	-60 °C	-120 °C
Heptane	C_7H_{16}	+120 °C	-40 °C

Tab. 5 Boiling and melting points of hydrocarbons

A simple division is as follows:

	C_1 to C_4	= gas
Approx. C_5	to approx. C_{12}	= benzine
Approx. C_{10}	to approx. C_{22}	= fuel oil EL/diesel
Approx. C_{20}	to approx. C_{35}	= lubricating and hydraulic oils
	Up to approx. C_{36}	= grease
	Above approx. C37	= vacuum residue

The approximate characteristic values in the following table are applicable for the most important hydrocarbons:

	Molecule size	Molecular weight	Boiling range	Flash point t°C	Density g/l
Benzines	C_5 - C_{12}	72 - 170	30 - 200	up to -50	715 - 790
Diesel, heating oil EL	C_{10} - C_{22}	142 - 310	180 - 360	58 - 65	820 - 860
Lubricating and hydraulic oil	C_{20} - C_{35} $C_{20}H_{42}$ - $C_{35}H_{72}$	280 - 455	210 - 600	100 - 260	840 - 910

Tab. 6 Characteristic data for various hydrocarbons (approximate values)

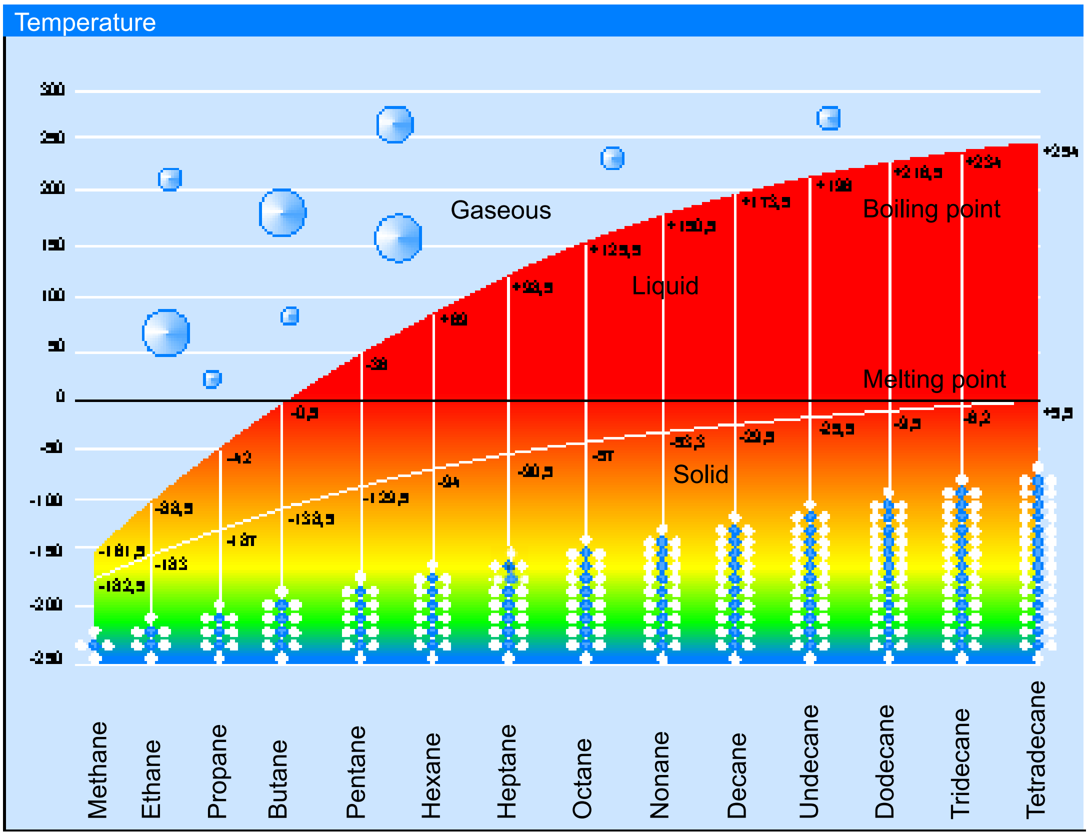
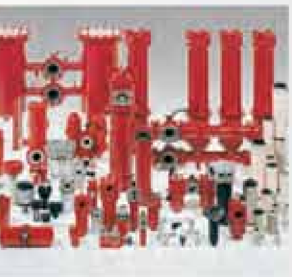


Fig. 25 Melting and boiling temperatures of normal paraffins (source: BP)


Accumulators DEF 3.000


Filtration Range DEF 7.000


Filters for Indust. Proces. DEF 7.700


Fluid Service DEF 7.929


Compact Hydraulics DEF 5.300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Prospekt: Elektronik DEF 18.000


Prospekt: Kühlsysteme DEF 5.700

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HYDAC INTERNATIONAL

HYDAC Systems & Services GmbH
Training Center

Hirschbachstraße 2
66280 Sulzbach/Saar
Germany

Phone:
+49 (0) 68 97 / 509 -01

Fax:
+49 (0) 68 97 / 509 - 1014

Internet: www.hydac.com
E-Mail: E-learning@hydac.com

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