Grinding Fluids for the Future

oelheld®
innovative
fluid technology

Helmut W. Ott
and
Dr. Manfred Storr

Grinding Fluids for the Future

Basic facts about grinding with oil

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1 Influencing Variables in the Grinding Process

1.1 Influencing variables

There is practically no other cutting procedure that can be compared to grinding in view of the number of its influencing variables. The very term used for grinding *„cutting with an undefined cutting edge"* suggests what is meant.

Any change in one of the parameters listed below can lead to a serious disturbance of the whole grinding process.

Figure 1

2 The Tribology of Grinding

2.1 Tribology

The abrasive grain´s penetration of the work piece surface initially leads to its flexible deformation. There is friction between the work material and the abrasive grain. In the second stage flexible and plastic deformation occurs. Only in the third stage does actual chip removal come about together with flexible and plastic deformation. Chip removal by the abrasive grain comes about at a negative angle with an undefined cutting edge.
If grinding oil is used as a cooling lubricant the friction between abrasive grain and work piece is reduced to a great extent.
In the third stage the work piece therefore bounces back, leading to a reduced thickness of the chips formed.

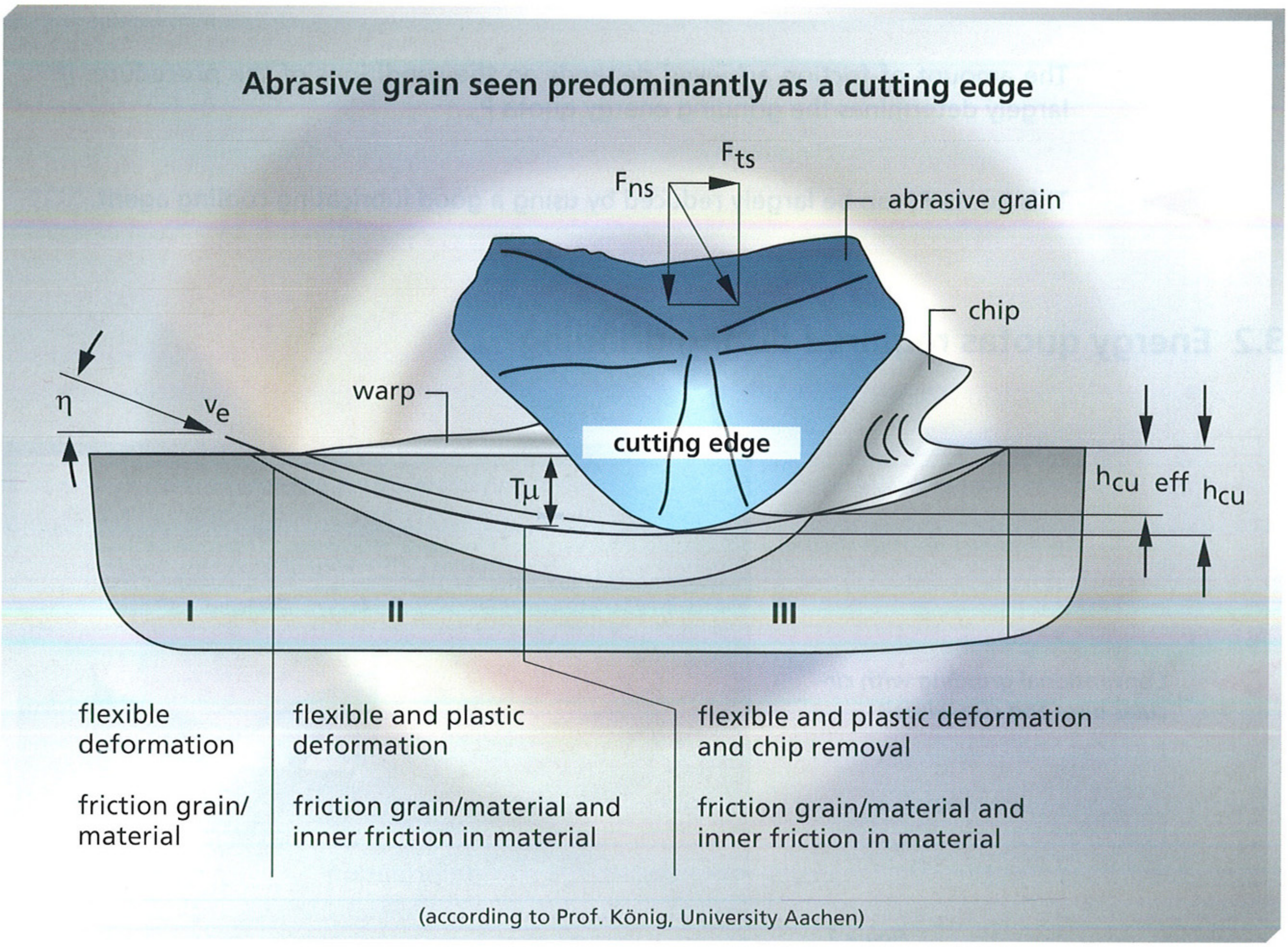

Figure 2

3 Thermal Economy During the Grinding Process

3.1 Heat balance during grinding

- About 90 - 92 % of the grinding energy quota P_s is transformed into heat by friction, crushing and deformation. Shearing action and chip deformation require the rest.
- Friction occurs mainly between the chip and the grain's cutting edge, but also at the clearance angle.
- Often the grain's cutting edge is unsuitable for chip formation due to its shape and position. It will only crush and plough on the surface of the work piece.
- The amount of friction achieved depends on the conditions of the procedure. It largely determines the grinding energy quota P_s.
- This quota P_s can be largely reduced by using a good lubricating cooling agent.

3.2 Energy quotas required during grinding

- *Conventional grinding with circular discs and cup wheels*

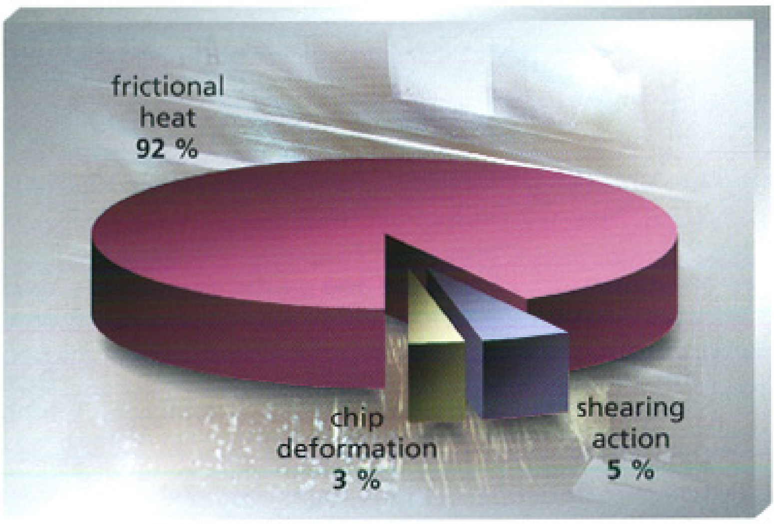

Figure 3

3.3 Heat distribution in the grinding contact zone

Examinations of heat distribution during conventional grinding with bad or insufficient cooling conditions have shown that 43 % of the heat flows into the work piece, 30 % into the chips and only 16 % is taken up by the cooling agent.

If cooling conditions are well adjusted to the grinding process 54 % of the heat is taken up by the cooling agent, 25 % by the chips and only 14 % by the work piece.

During high speed grinding 60 % of he heat is taken up by the chips, 26 % by the cooling agent and only 3 % gets into the work piece.

3.3.1 Heat distribution during conventional grinding with circular discs and cup wheels

<u>Bad or inadequate</u> cooling conditions

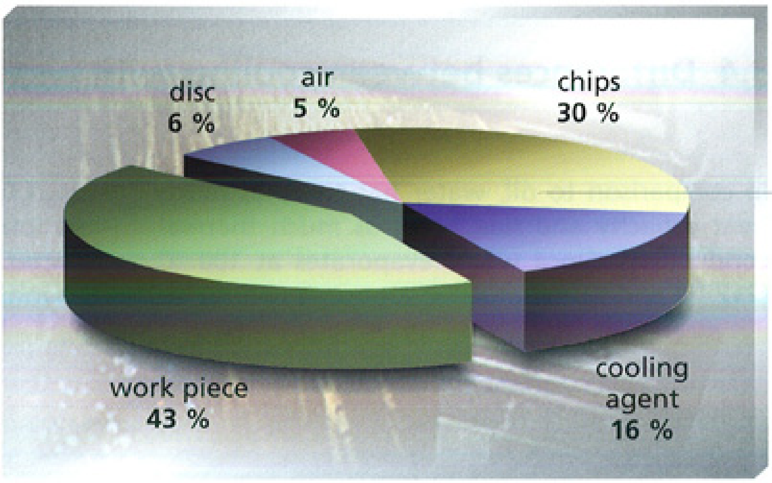

Figure 4

Cooling conditions that are <u>well adjusted</u> to the process

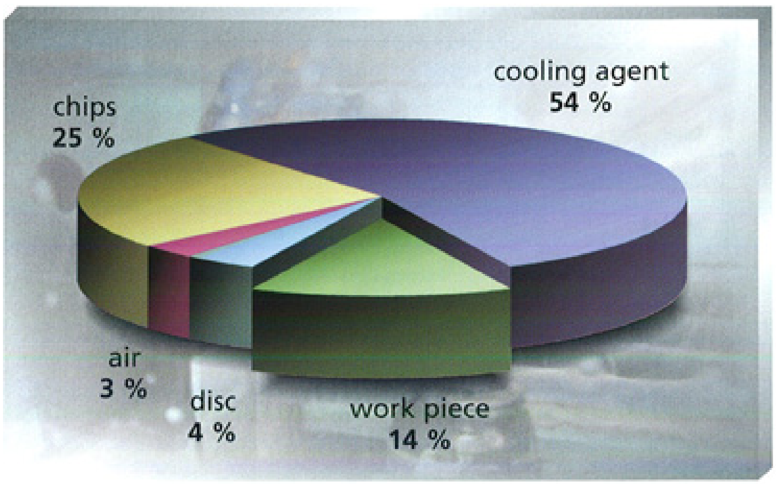

Figure 5

3.3.2 Heat distribution during high speed grinding with circular discs (v_c>=100m/s velocity)

Optimised cooling conditions are an absolute necessity here

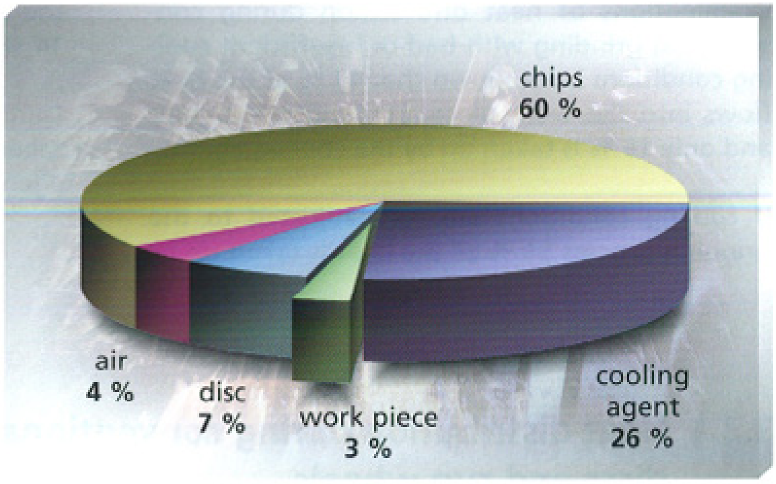

Figure 6

3.4 Differences between cooling with water and oil

In comparison to oil, water has twice as much heat capacity and five times as much thermal conductivity. Since water evaporates at 100 °C (212 °F) and turns to water vapour, it cannot be used for high speed grinding. Water vapour has no lubricating effect and is a poor thermal conducter. Very thinbodied oil on the other hand has an initial boiling point of over 240 °C (464 °F).

COMPARISON		OIL	WATER
specific heat	J/g K	1,80	4,20
and			
thermal conductibility	W/m k	0,13	0,60

Figure 7

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4 Cooling Lubricants

4.1 Classification of cooling lubricants according to VDI guidelines 3396

The VDI guidelines distinguish cooling lubricants that cannot be mixed with water from those that can. The latter are again divided into emulsions and solutions.

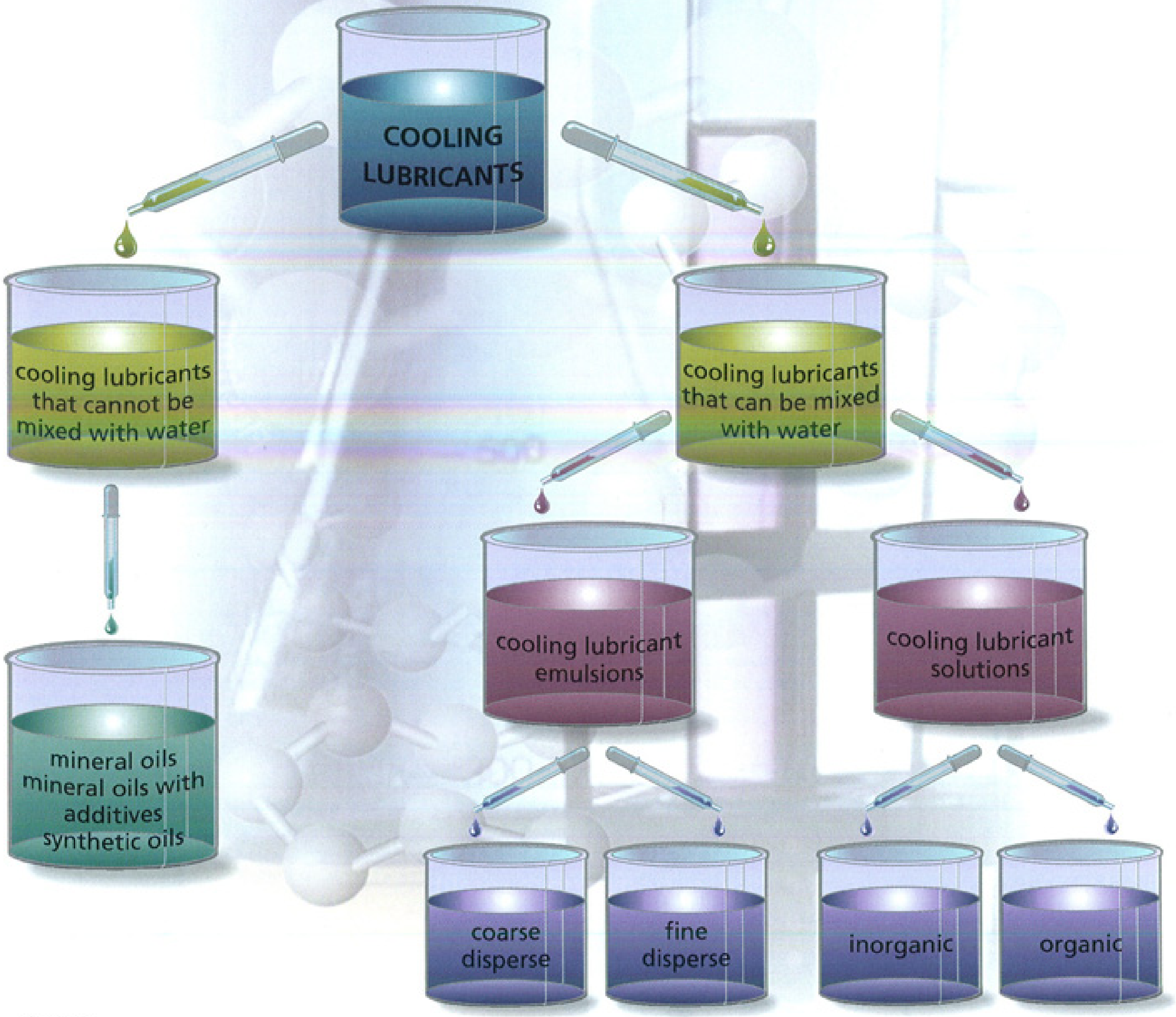


Figure 8

4.2 The functions and the purpose of using cooling lubricants

Among the functions of cooling lubricants are lubrication, cooling, cleaning and protection from corrosion. Cooling lubricants are used to increase the speed of operation and improve surface quality, while at the same time protecting the tools. The final aim is to reduce running costs.

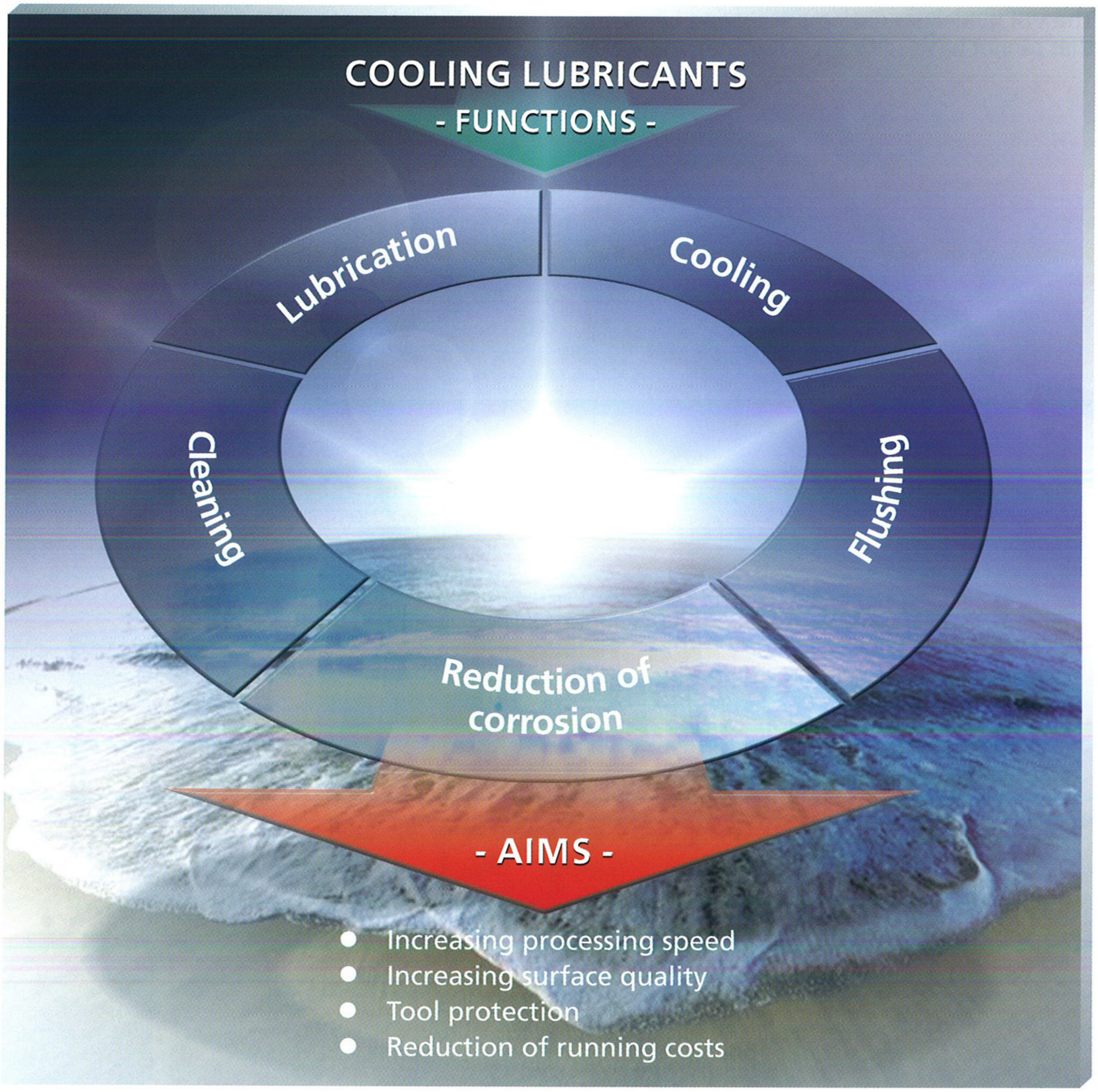


Figure 9

4.3 Advantages of grinding with oil

While cooling lubricant solutions and emulsions are often used during conventional grinding processes - especially for cooling purposes - cooling lubricants with special friction reducing properties, i.e. cooling lubricant that cannot be mixed with water, are used predominantly as grinding speed increases. This has great advantages.

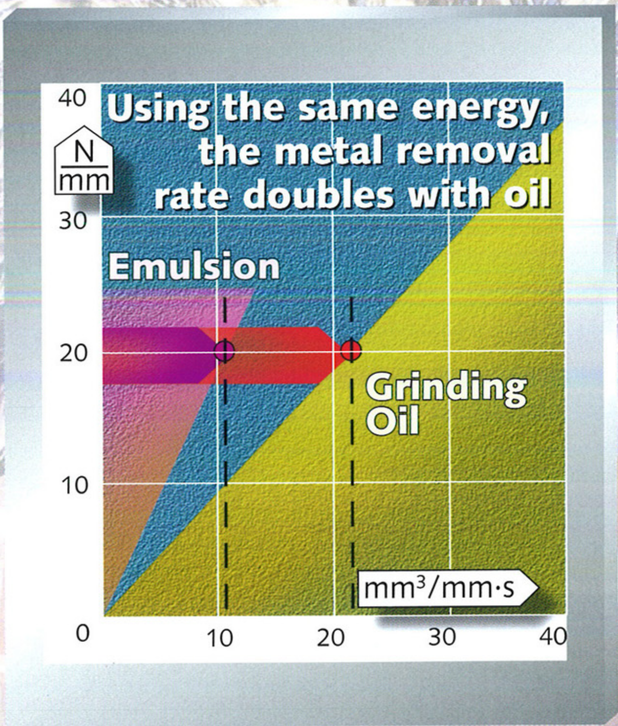


Figure 10

Better performance

When using oil instead of water mixable cooling lubricants the rate of metal removal can be doubled or tripled and operating time is reduced. If the rate of metal removal is retained the energy required by the machine will be reduced by about 60 %. This statement is valid for all work pieces made from steel or HSS.

Figure 11 on page 12 shows energy demand relative to the cooling lubricant used. The higher the lubricating effect of the cooling lubricant, the lower will be the energy demand. Clearly, dry grinding requires the most energy. A grinding oil that contains ANTIWEAR and EXTREME PRESSURE additives requires the least energy.

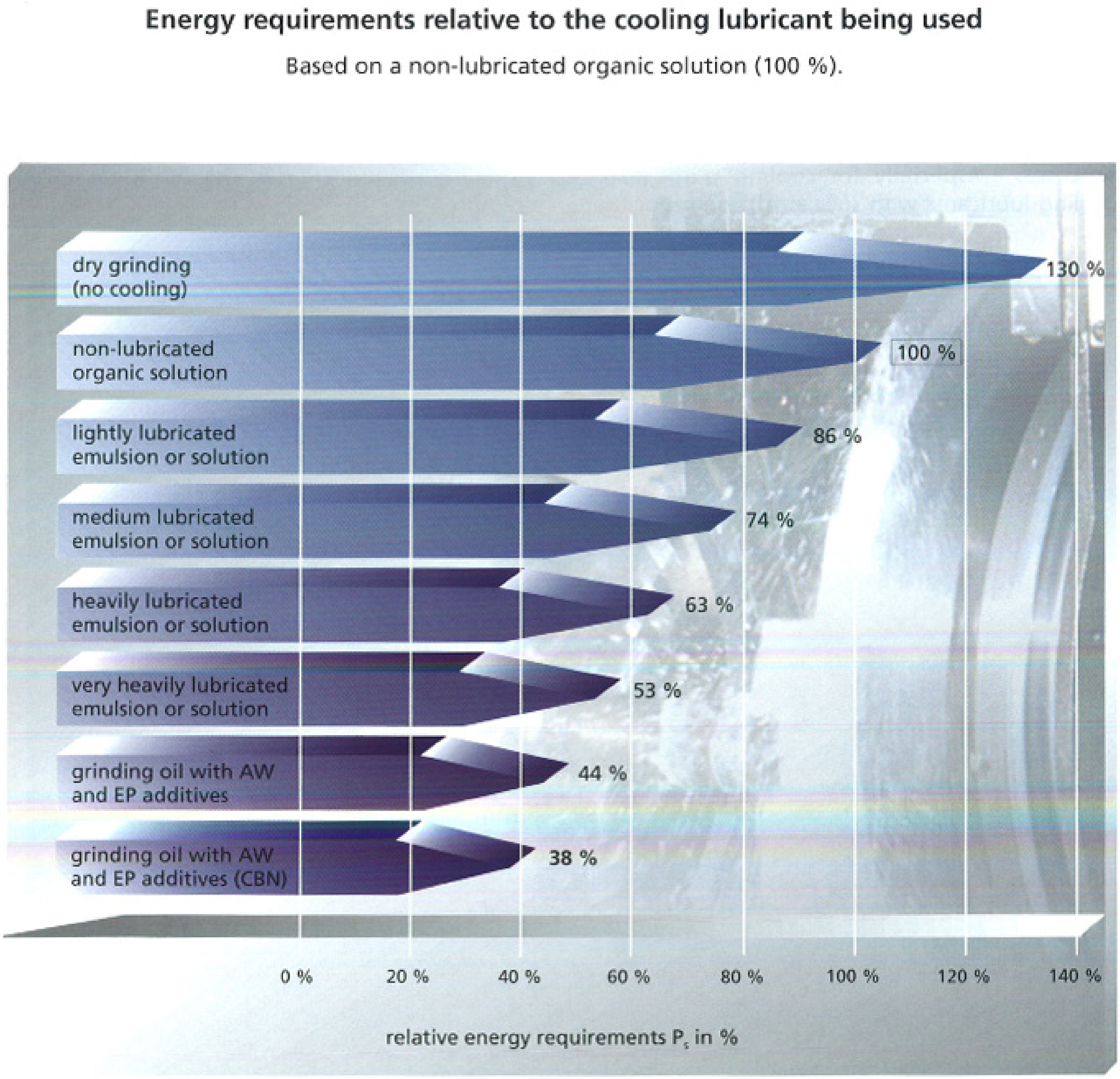


Figure 11

When processing hard metals with diamond cutters, performance can only be improved slightly, because grinding speed must remain under 30 m/sec to avoid overheating. At temperatures of over 750 °C (1382 °F) the diamond will disintegrate into a carbon grid. The diamond attains its highest effective hardness at about 25 m/sec. Only during point contact and with a disc diameter of 400 mm can grinding speed be increased to 140 m/sec.

Measurements of the effective tangential force also showed that highest tangential force is needed during dry grinding and the least tangential force is needed with a highly alloyed grinding oil (see figure 12 ond page 13).

Effective tangential force F_t and normal force F_n depending on the cooling lubricant being used

A given grinding process that is carried out with various cooling lubricants - or none at all - serves as the basis of calculation.

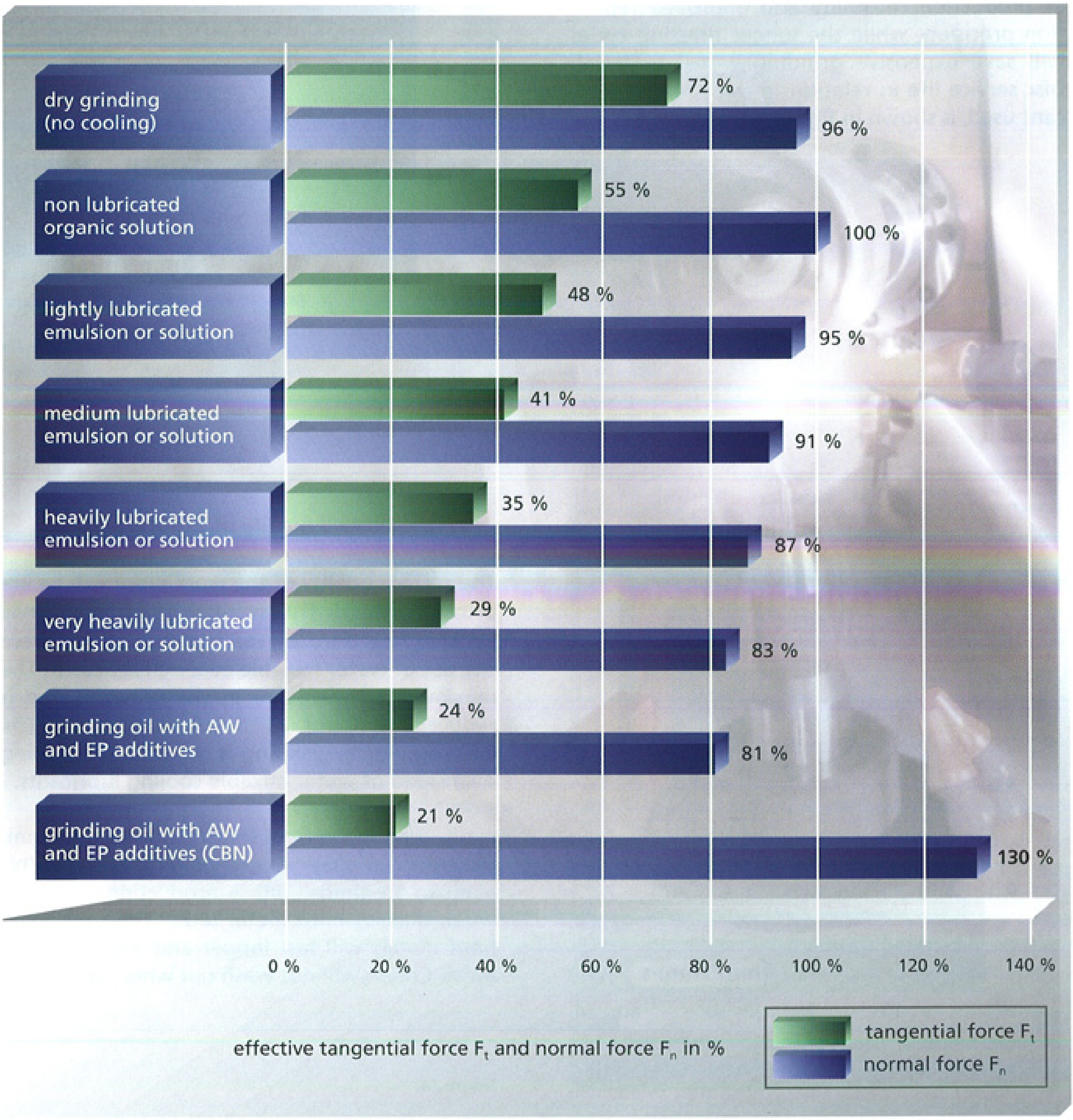


Figure 12

Less wear on grinding wheels

With oil, expensive grinding wheels will last up to five times as long. The dressing cycles lengthen considerably. This is true for corundum, CBN and diamond grinding wheels. The whole grinding process will be characterized by greater production reliability and improved repetition precision, while the longer dressing cycles will save expensive grinding wheel material. Disc service life in relation to the cooling lubricant used, is shown in figure 15 on page 15.

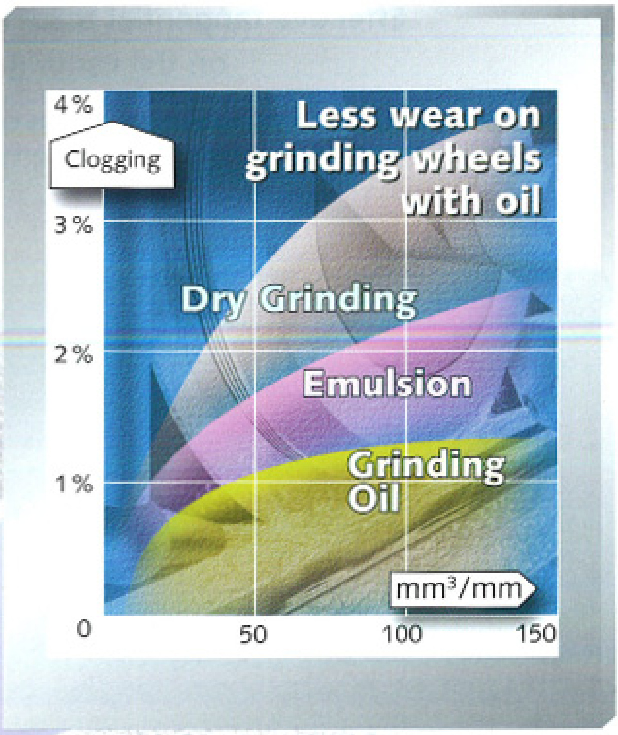
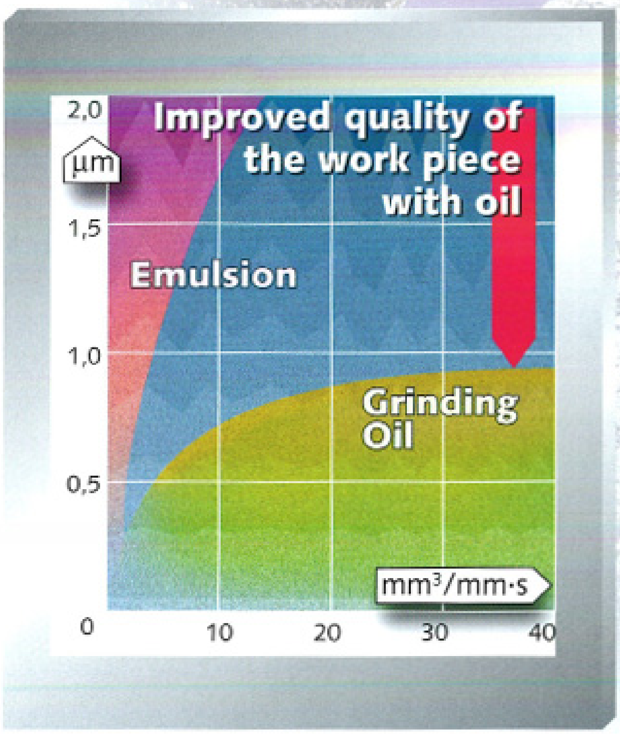


Figure 13



Improved quality of the work piece

The surface quality of the work piece will be improved with oil. The average roughness R_a will be only one third of the figure resulting from the use of water mixable cooling lubricants. The maximum temperature in the grinding gap is reduced by about 25 % when using oil. The burning during grinding is reduced when using oil instead of water mixable cooling lubricants.

A decrease in thermal shock leads to fewer microstructural changes (no hairline cracks). This leads to an almost 100 % production reliability when making hard metal tools. The coating of hard metals will last longer and will not flake away. Cobalt will not wash out when using oil.

Figure 14

Relative disc service life in relation to the cooling lubricants used (averages)

Grinding oil with additives is used as a basis (100 %).
The diagram is only valid for conventional grinding wheels!

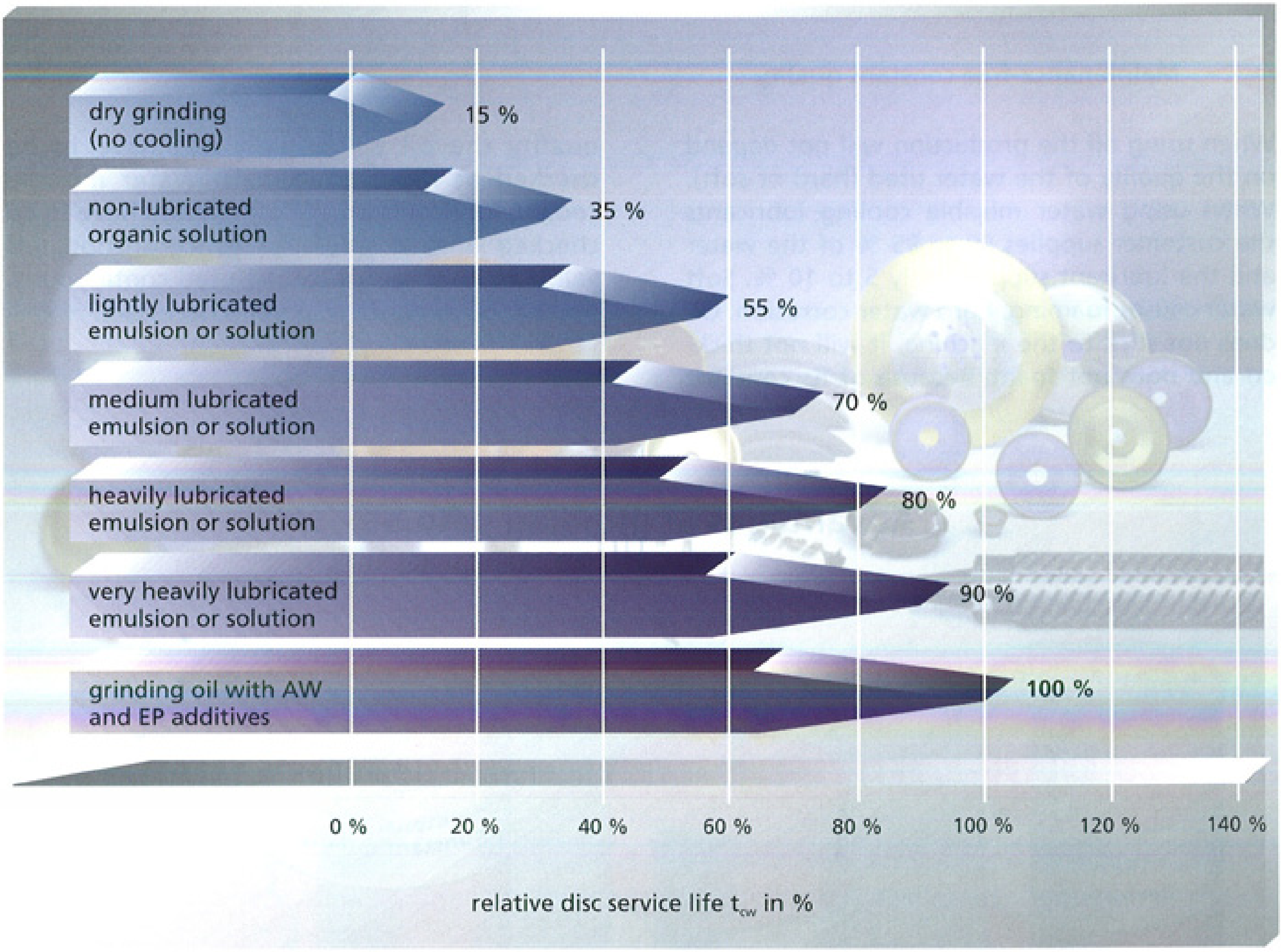


Figure 15

Machine care

Oil will lubricate all the other machine elements as well and will not damage slideways. It offers optimum protection against rust. When using water mixable cooling lubricants the vapour produced causes problems with rust formation. When using oil the appearance of a grinding machine will be very good even after many years. There will be no damage to varnish nor corrosion. When grinding hard metals no *„black layer"*, which can lead to machine failure, will form. Oil guarantees constant readiness of the machine and will reduce down times.

Health aspects

Oil contains no biocides. It is not attacked by bacteria, fungi or yeast. No additional costs for conservation with biocides after the procedure will occur. When using oil there is no danger of nitrous amines forming (nitrous amines are considered to be cancerous!). Oil will not dissolve heavy metals (e.g. cobalt ions in emulsions or solutions). The occurence of skin disease among the staff will be decreased by 80 to 90 %.

Maintenance-free constant quality

When using oil the production will not depend on the quality of the water used (hard or soft). When using water mixable cooling lubricants the customer supplies 90 to 95 % of the water and the lubricant supplier only 5 to 10 %. Soft water causes foaming, hard water corrosion. Oil does not stick to the machine, it will not thicken and does not foam. Because of its constant quality the oil will usually not have to be checked at regular intervals. Water mixable cooling lubricants on the other hand have to be checked once a week for concentration, pH value and nitrite. Oil can be used continuously. No change or waste disposal is necessary.

Advantages of grinding with oil

Figure 16

4.4 Conditions for grinding with oil

Encapsulation

Before oil is filled into a grinding machine its encapsulation must first be checked. The capsule prevents oil from seeping out. Most new grinding machines are fully encapsulated.

Suction mechanism

In addition the machine should have a suction mechanism to suck out oil gas, mist and smoke, so that they will not irritate the machine operator. Air filter systems with deflectors and filtering mats as well as electrostatic filter systems with additional activated carbon filters are well proven in practice. When using electrostatic filter systems it is to be recommended that a service contract is made, so that the high-voltage part will be cleaned regularly.

So called demistors are well suited for large central ventilation systems in factories. They clean the air by spraying oil on wire nettings.

Suction flaps

Suction flaps must be fitted to the top of the machine to carry off the energy in the extremely rare case of an explosion. The flaps must be so adjusted that they will close by themselves after an explosion and automatically stop suction. They are common on most new machines.

Fire extinguisher

Oil is flammable! Every machine must therefore be equipped with an automatic fire extinguisher.

Application of cooling agent

The grinding wheel and the work piece should be well flooded with cooling lubricant to avoid the danger of an explosion. Pressure of only about 2-3 bar is needed for a fan-type nozzle.

Control of cooling agent

A flow control instrument must switch off the machine immediately, if the cooling agent should fail. An additional level control instrument can prevent a mixture of oil and air being pumped into the grinding contact zone.

Oil resistance

All hose pipes, cables and seals, as well as stop switches that are made from plastic, elastomer or rubber must be oil resistant.

Cooling lubricant amount

Because of the lower heat capacity of oil in comparison to water mixable cooling lubricants, the amount of cooling lubricant used should be doubled. If the same amount is used, a cooling unit should be built in.

Cooling Lubricants

Conditions for grinding with oil

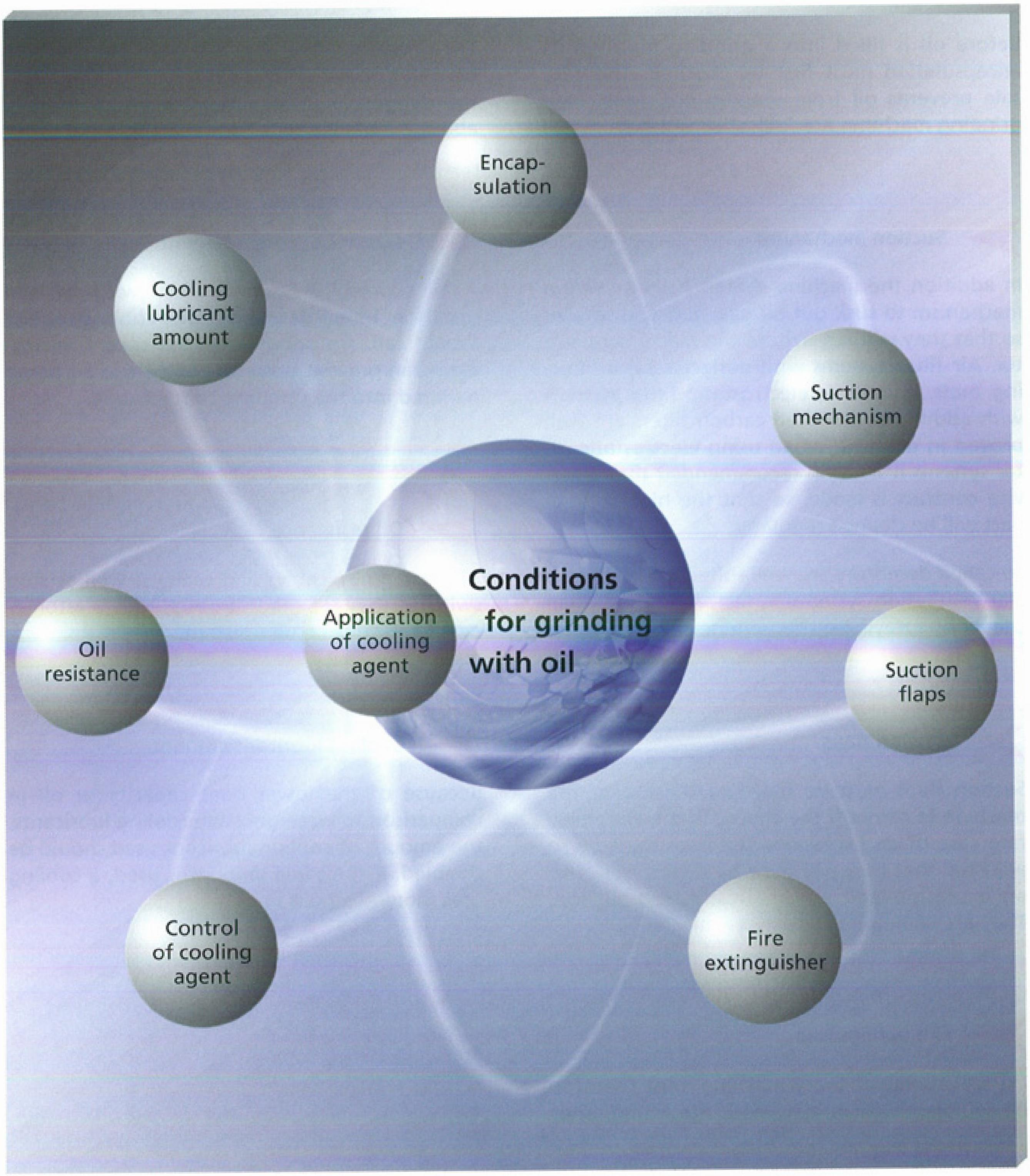


Figure 17

4.5 Composition of grinding oils

4.5.1 General remarks

In principle grinding oils are always made from a suitable basic fluid with various additives, depending on the purpose they have to serve and the demands they have to meet. This basic fluid can be produced by distillating and refining crude oil or it can be made synthetically from gases in a synthesizing oven using a catalyst and the influence of pressure and heat.

Synthetic products guarantee a degree of purity that is insurpassable. Linear molecular chains that are best suited for the purpose intended can be precisely formulated.

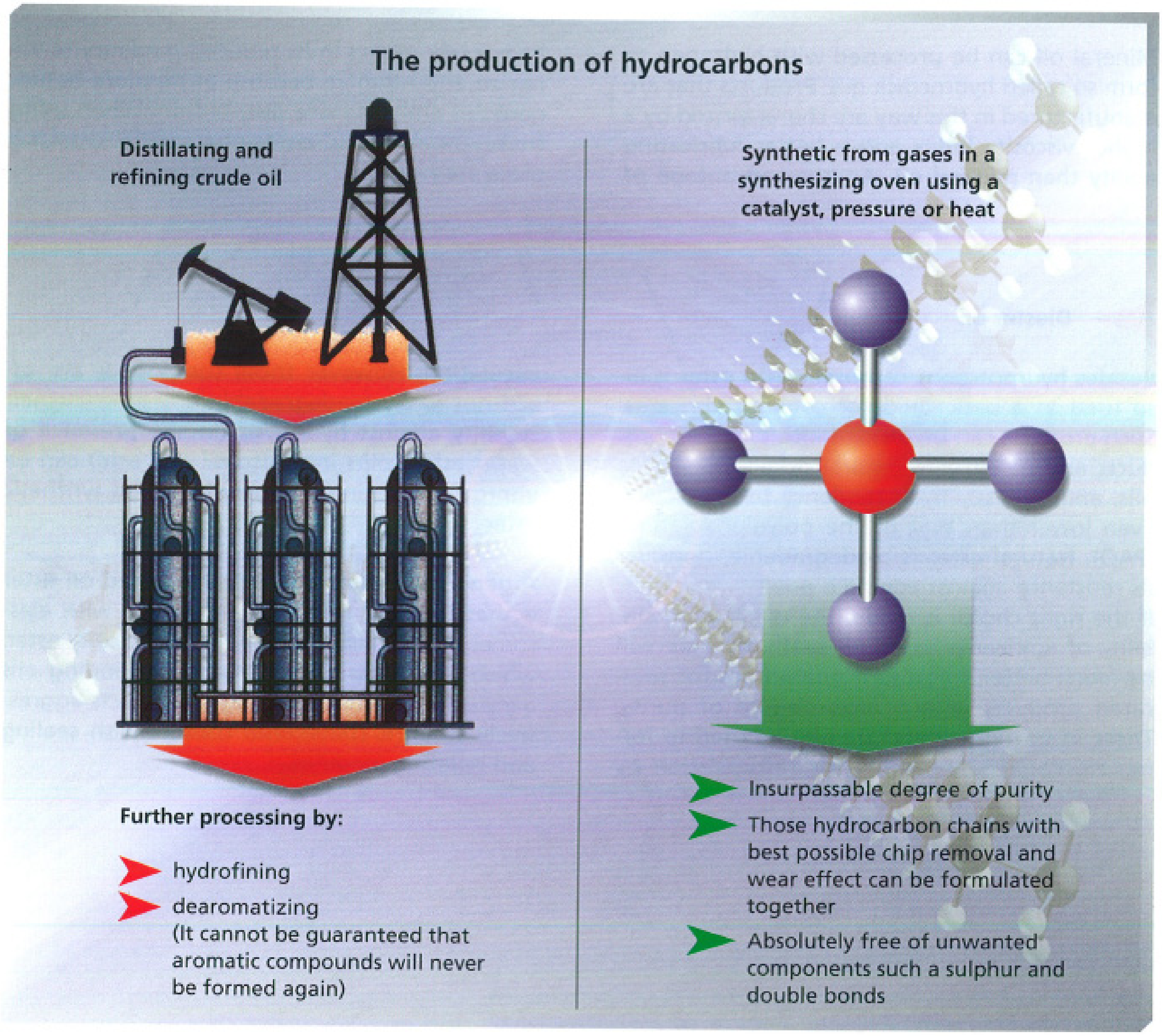


Figure 18

4.5.2 Basic fluids

Mineral oil

Most of the hydrocarbon basic fluids in use today are still refined mineral oils produced directly out of crude oil. They consist of a colourful mixture of chain and ring hydrocarbons and contain double bonds that break apart when heated, causing the cooling lubricant to age quickly and dangerous compounds to form.

Hydrocrack oil

Mineral oil can be processed with hydrogen to form so called hydrocrack oils. Products that are manufactured in this way are characterized by a higher viscosity index and a better lubricating ability than mineral oil. Another advantage of hydrocrack oil lies in its reduced tendency to vaporize and atomize because of its more homogeneous molecule size distribution. When using these products HC-emissions at the working place are reduced.

Diester oil

Besides hydrocarbons carboxylic acid ester is also used as a basic fluid for cooling lubricants. Such products can be divided into synthetic products and those of a natural origin (vegetable oils, animal fats). Their tendency to vaporize is even lower than that of the polyalphaolefines (PAO). Natural ester is biodegradable, however its resistance against ageing is poor.
If the right choice is made, the oxidization stability of lubricants based on synthetic ester will be much better, because it guarantees for saturated products with a high degree of purity. These in turn can therefore also be used to formulate cooling lubricants for refrigeration by circulation. However these compounds are often not easily biodegradable any longer. Their stability against hydrolysis (in the presence of water ester splits into alcohol and acid) can be improved by using sterically hindered synthetic ester.

A general problem of lubricants based on ester is that they are not fully compatible with elastomer and varnish. Especially low viscosity ester, which is used as a basic fluid for grinding oils because of its good flushing ability, acts aggressively when it comes into contact with sealing and isolating material.

Polyalphaolefine (PAO)

Polyalphaolefines are synthetically produced lubricants with excellent qualities. They are used as basic oils in racing sport under the extreme conditions of the "Formula 1". As cooling lubricants they excell because of their minimal evaporation rate, high flash point together with low viscosity and large viscosity index. They are characterized by excellent shearing resistance and ageing stability. Because of their uniform composition the PAOs´ tendency to evaporate is markedly lower than that of hydrocrack oil. Cooling lubricants based on polyalphaloefines are excellently suited for high speed grinding processes. If a suitable formula is used these cooling lubricants are even biodegradable.

Molecule model of a polyalphaolefine (PAO)

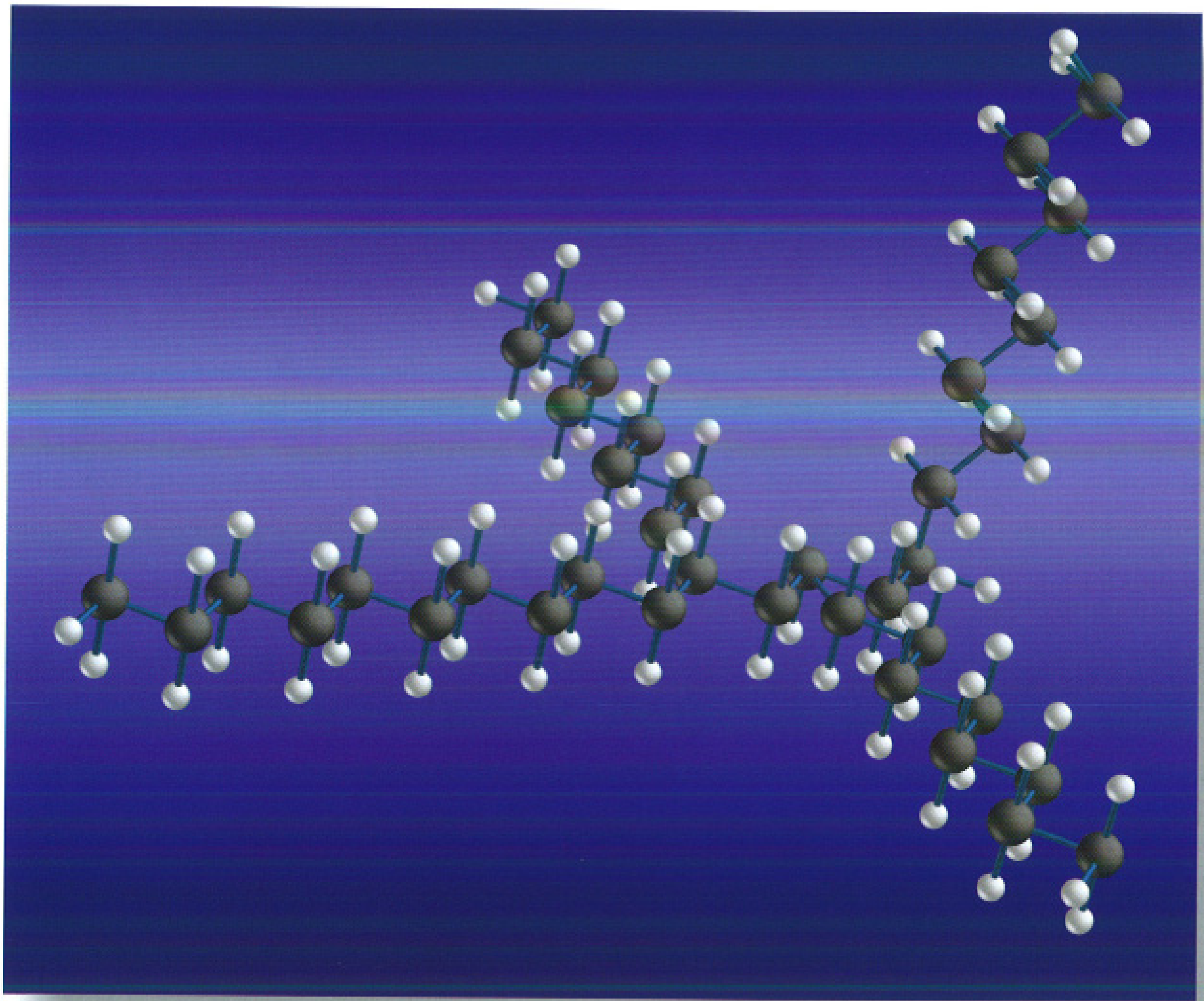


Figure 19

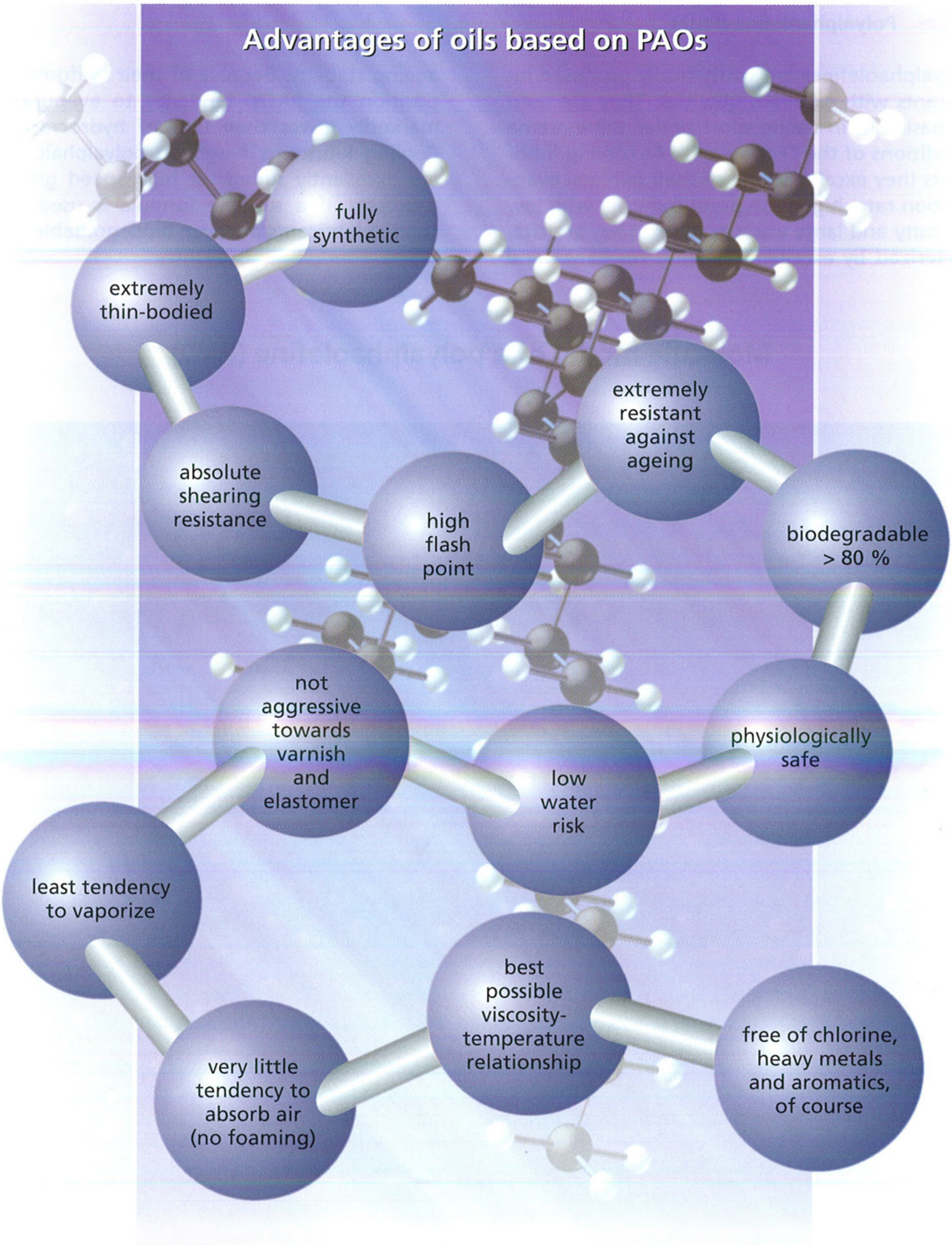

Advantages of oils based on PAOs
fully synthetic
extremely thin-bodied
absolute shearing resistance
high flash point
extremely resistant against ageing
biodegradable > 80 %
not aggressive towards varnish and elastomer
low water risk
physiologically safe
least tendency to vaporize
very little tendency to absorb air (no foaming)
best possible viscosity-temperature relationship
free of chlorine, heavy metals and aromatics, of course

Figure 20

4.5.3 Additives

Suitable additives can further improve the physiological and chemical qualities of basic fluids and optimize them for processing.

Friction modifier

Friction modifiers are deposited on metal surfaces and decrease the friction between them. Besides the carboxylic acid ester described above and fatty alcohol, carboxylic acid, amine and amide compounds are used for this purpose.

Anti-wear additive

Anti-wear additives react with metal surfaces and form plastic deformable layers, which decrease the wear between the tribologically stressed friction partners. These components are divided into ash producing and ashfree products.

EP additive

Extreme-pressure additives (EP additives) react with metal surfaces and form compounds with less shear resistance, thus preventing microbonding from occurring between metal surfaces, when pressure and temperatures are high. There is no clear dividing line between anti-wear and EP additives; in both cases reactive phosphoric compounds are used, as well as organic sulphuric compounds, in which case sulphuric hydrocarbons (polysulphides) are differentiated from carboxylic acid ester converted with sulphur. Both types settle on metal surfaces and decompose at higher temperatures. The so called active sulphur additives react much more quickly than the inactive kind. Together with the metal the sulphur that is released in this way forms sulphides, which have a much lower shear resistance than the metal itself. This effect causes a better removal of the work material and prevents it from bonding with the tool´s cutting edge. The organic compounds of chlorine (chlorinated paraffin) that was used a great deal until a few years ago, is not considered safe from an ecological and toxicological point of view any longer and has been largely replaced by sulphuric compounds.

Antioxidantine

The ageing of lubricants is caused especially by contact with the oxygen in the air. In particular cooling lubricants for high speed grinding operations are usually exposed to high temperatures. A negative effect of this oxidization is an increase of acid components and thus increased aggressivity towards varnish, elastomer and metal. In addition cooling lubricant components that have aged can resinify and cause an unpleasant sour smell.

Anti-vapor additive

To prevent excessive vaporization occuring during heavy swirling, oil soluble chain polymer compounds are added to the products. They prevent a too fine distribution of the oil vapour.

5 Safety Precautions When Using Grinding Oils

5.1 Research into the fire and explosion hazard

Oil with a flash point of over 100 °C (212 °F) is usually used for grinding. Regulations for inflammable fluids therefore do not apply to it.

Every oil has a so called *„lower"* and an *„upper"* explosion limit. These limits are defined according to the percentage of oil in the air.

Usually the lower explosion limit lies at 0.6 vol. %/air. That means that an oil/air mixture below this limit is not inflammable (e.g. when lubricating minimal amounts).

The upper explosion limit lies at 7 vol. %. That means that if there is an oil/air mixture above this limit there will be no ignition - the mixture is *„too greasy"*.

An oil/air mixture can thus only be ignited if the relationship of oil to air lies between 0.6 and 7 vol. %/air. This dangerous range must be avoided e.g., by flushing the grinding zone very well. Atomization of the oil must be minimized by a suitably constructed nozzle.

View of the self-contained experimental set-up, with storage tank, pump and compression-proof container (Physikalisch Technische Bundesanstalt in Braunschweig, Germany, 1997)

Figure 21

In 1997 a government approved testing agency (the Physikalisch Technische Bundesanstalt in Braunschweig, Germany) tested several types of oil with various kinds of chemical composition (mineral oil, hydrocrack oil, polyalphaolefine, ester) with flash points from 120 °C (248 °F) to 240 °C (464 °F). Viscosity at 40 °C (104 °F) was between 3.6 and 30 mm^2/s. The tests were conducted in an experimental set-up with a 700 litre compression-proof container, into which the oil was sprayed at 0.5 to 10 bar through a full centerbody nozzle. The oil/air mixture was ignited by means of electricity.

5.1.1 Research results

- The mist from all the cooling lubricants tested could be ignited with an electrical spark of less than 10 J in the experimental set-up, even if their flash point was over 200 °C (392 °F).

- The maximum overpressure registered was between 3.5 and 4.5 bar.

- The cooling lubricant spray could not be ignited by a steel grinding spark formed by a corundum grinding wheel at a pressure of up to 600 N/cm^2 and 30 m/s grinding speed. Titanic grinding sparks however ignited the spray irrespective of the cooling lubricant used.

- The spray from all the tested cooling lubricants could be ignited by small heated rods. Ignition only came about at temperatures of 800 °C (1472 °F) to 1000 °C (1832 °F), however, which is far above the normal ignition temperature of fluids.

- It was possible to prevent ignition by using a flooding stream from a ring beam nozzle, if the friction area was totally flooded. If flooding was incomplete, however, an ignition of the mist formed by secondary atomization at the friction point was possible.

5.1.2 Causes of fires and explosions

Fortunately fires and explosions are extremely rare when grinding with oil. In addition there is never any danger for the machine´s operator, because no more than an overpressure of 4.5 bar is ever reached. When grinding hard metals there is even less danger, as there is no *„tail of a comet"*, which could lead to an ignition of the oil/air mixture.

Between 1987 and 1994 the VDMA examined 150 fires and explosions, which had the following main causes:

The work piece jammed

The jamming of the work piece caused local overheating, which in turn led to ignition.

The oil supply failed or was reduced

Normally a sensor will stop the grinding machine immediately, if its oil supply should fail or be reduced. Where this did not happen, the lack of oil cooling led to overheating in the grinding process: the machines began to burn. This is particularly dangerous if the lack of oil also causes the machine´s supply pump to bring air into the grinding contact zone, or if no oil at all gets into the contact zone because of a faulty adjustment of the nozzle.

There was an error in machine control

The operator programmed the machine wrongly and it began to grind the work fixture instead of the work piece. Fluctuations in electricity can also lead to an interruption of the control mechanism leading to faulty machine movements.

Grinding wheels with a steel core were worn down

The grinding wheel had lost its coating. As a result, friction between the steel core and the work piece led to overheating until the work piece glowed.

5.2 Health aspects when grinding with oil

The grinding process influences the environment and human beings in many ways. As far as human beings are concerned, such influence occurs mainly when gas, mist and smoke are breathed in, dust and fluids are swallowed, or fluids are absorbed through the skin.

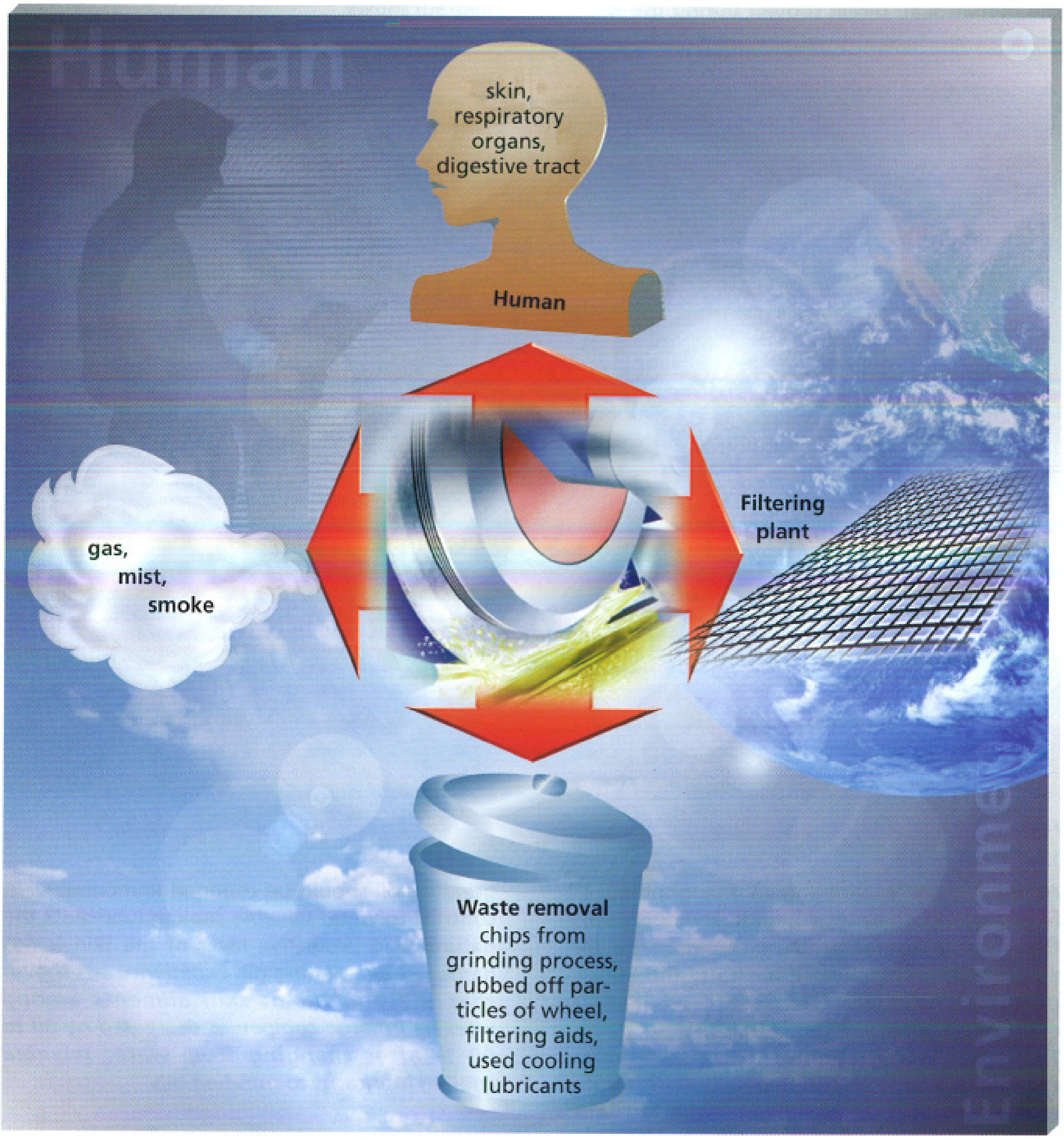


Figure 22

5.2.1 Grinding oil and the human skin

With reference to decades of experience and because of its chemical composition (no aromatics in polyalphaolefines) it can safely be maintained that oil has no damaging effect on the human skin. Direct contact during the work process occurs practically exclusively through the hands.

The skin is the largest organ in humans and its structure is very complicated, as the following diagram shows.

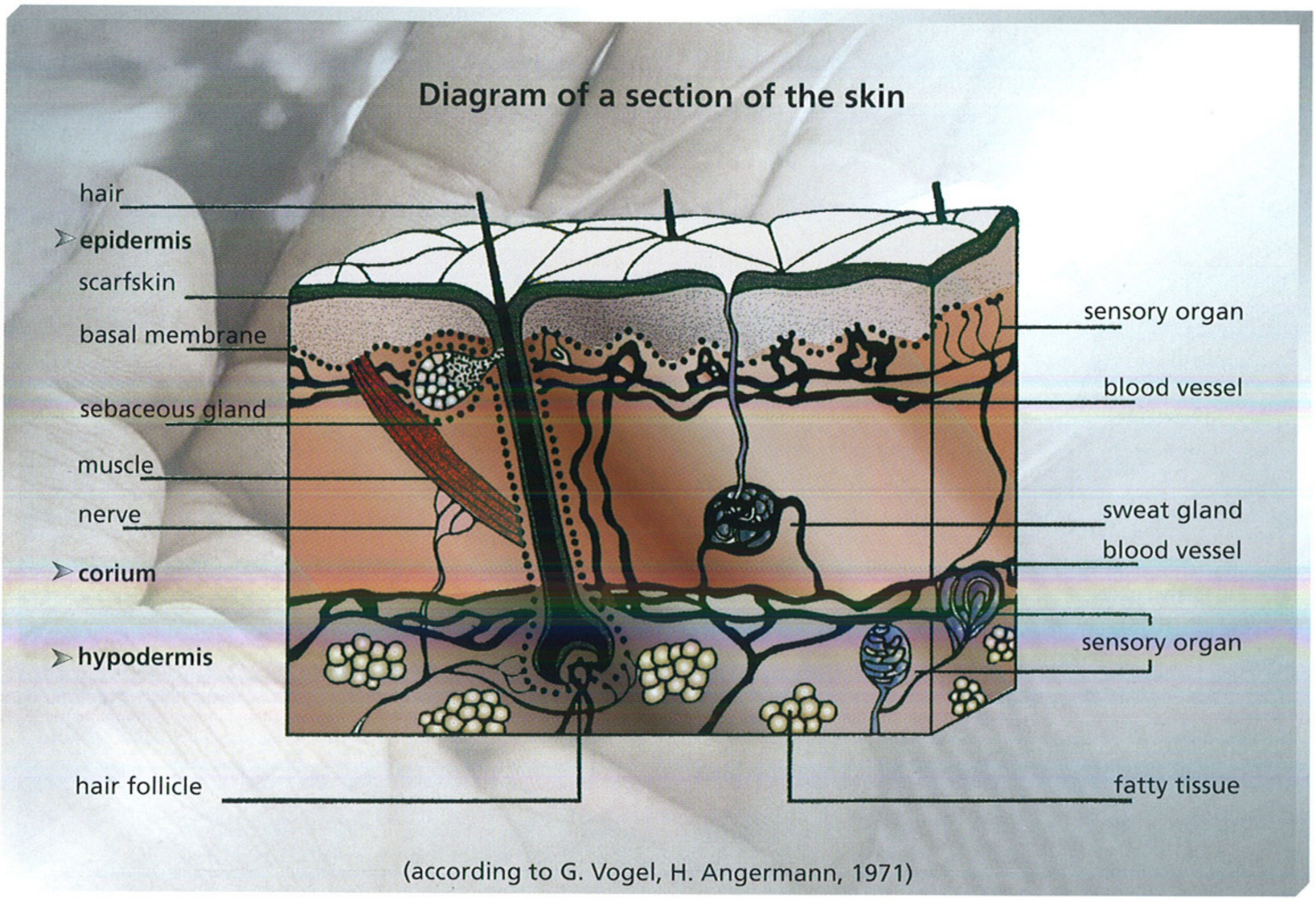


Figure 23

Abrasive particles floating in the grinding oil (e.g. tiny chips) have a negative influence on the skin, in so far as they can damage the epidermis mechanically. Cobalt and nickel particles penetrate the pores and lead to allergies. In general it can be said:

The better the filtration of the grinding oil is, the less will be its mechanical influence on the skin. Clothing that has been saturated with grinding oil should be changed immediately. In contrast to water mixable cooling lubricants the natural acid protective layer of the skin is not damaged by grinding oil. *Experience has shown that the amount of skin ailments among workers in large companies decreased by 80 to 90 % after changing from water mixable cooling lubricants to grinding oils.*

5.2.2 Effects on the human organism

To avoid oil gas, oil mist and smoke from influencing the human organism during a grinding process with oil, the machines used must be encapsulated and have a suction mechanism.

The maximum MAK-value (maximum concentration at working place) is at present considered to be 10 mg oil mist and oil gas per m^3 breathing air. One must differentiate between:

Oil gas

It is invisible and is formed when oil is heated to about 250 °C (482 °F). When using water mixable cooling lubricants such gas forms at 100 °C (212 °F) already and will exceed the amount of gas caused by grinding oil many times over. Grinding oil based on polyalphaolefines has an evaporation loss of two thirds less than customary mineral oil products.

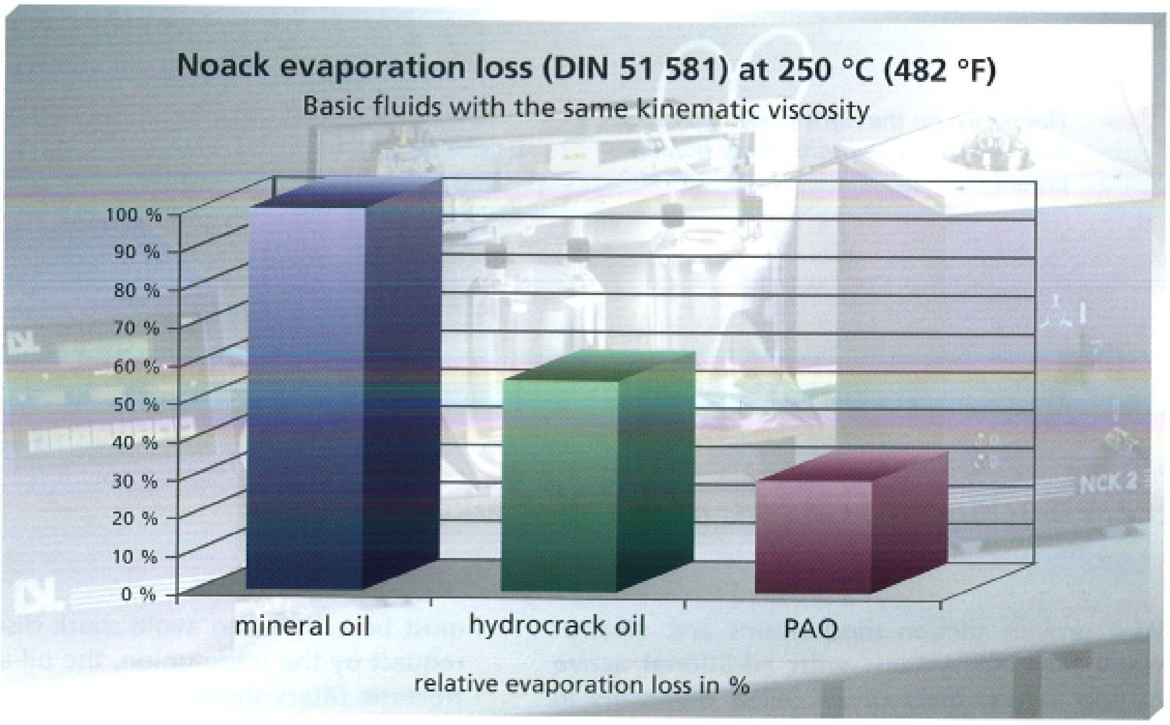


Figure 24

Oil mist

Oil mist consists of very finely distributed oil drops in the air. In this respect as well, the products based on polyalphaolefines, which have very little evaporation loss, are far superior to mineral oil products.

Smoke

Grinding smoke consists of finely dispersed solid material that can come from work material, grinding wheel material and burnt oil.

5.2.3 Deposits of gas, mist and smoke in the human organism

Research which was carried out with the help of a gamma camera to determine what gas, mist and smoke deposits are brought about by working with cooling lubricants showed that much of it was deposited, as expected, in the throat, nose and upper respiratory organs. The lung was also affected. Even the stomach showed a strong concentration of cooling lubricant.

The sketch on the right shows typical gas, mist and smoke deposits in the human organism.

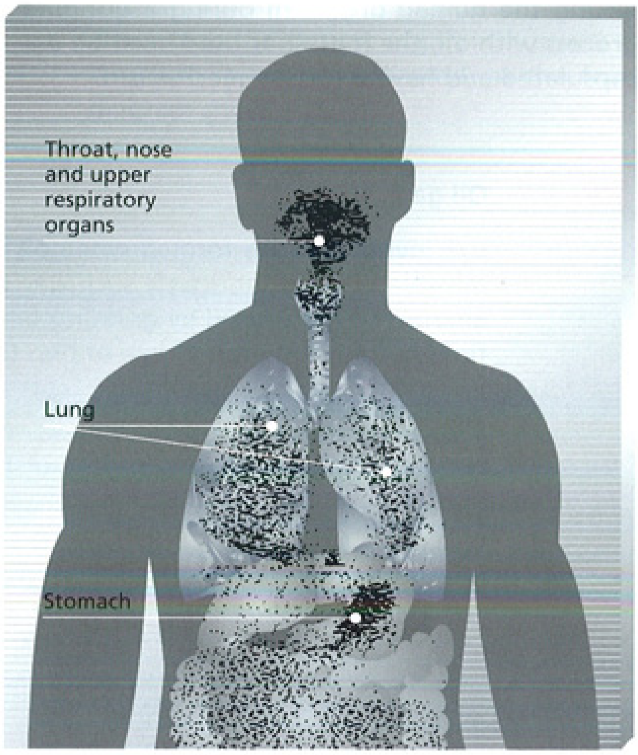


Figure 25

5.2.4 Sucking off oil gas, mist and smoke

Well proven suction mechanisms are: electrostatic filtering systems with additional active carbon filters, mats or so called demistors in large plants (see also 4.4 above). In electrostatic filtering systems cleaning at regular intervals must be ensured to avoid spark discharges. On request by the trade union, the oil used in electrostatic filters should have a flash point of at least 140 °C (284 °F).

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Dr. Manfred Storr

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oelheld GmbH
innovative fluid technology
Ulmer Straße 135-139
D-70188 Stuttgart
Phone: +49 (711) 1 68 63 - 0
Fax: +49 (711) 1 68 63 - 40
E-mail: hutec@oelheld.de
www.oelheld.de

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For more information, please contact us:

oelheld GmbH
Ulmer Straße 135-139
D-70188 Stuttgart
Phone: +49 (711) 168 63 - 0
Fax: +49 (711) 168 63 - 40
E-mail: hutec@oelheld.de
www.oelheld.de

oelheld (U.K.) Ltd. Lubricants Div.
Unit 16, Colomendy Bus.Park,
Rhyl Road, GB Denbigh LL16 5TA
Phone: +44-1745-814 777
Fax: +44-1745-813 222
E-mail: sales@oelheld.com
www.oelheld.co.uk

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