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ARTHUR RUSHMER ENGINEERING ENT cc
THE BEST SOLUTION
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LLOYD'S REGISTER QUALITY ASSURANCE ISO9001
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THE LUBRICATION OF ROTARY VANE COMPRESSORS

1. **Functions of the lubricant**

The oil serves 4 main functions:

A) LUBRICATION of
- Stator/ vanes (reduces wear)
- Vanes/ oil grooves / rotor (prevents shellacking)
- White metal bearing bushes

B) SEALING
- Reduces friction within the stator and on vanes
- Seals between rotor/stator

C) COOLING
- Removes maximum heat from the compression chamber and Transfers it to the heat exchanger

D) PROTECTION
- Inhibits corrosion of metals

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2. **The lubricant must not form …**

Ø varnish – deposits – sludge

- In order to keep the Separator filter: clean and efficient
- To keep Vanes/blades and their oil grooves or ports: lubricated without Varnishing/discoloring and all Hydraulic Valves: clean and efficient

3. **The lubricant must not …**

Ø deteriorate rapidly

Temperature, the interaction of oxygen-humidity and mechanical shearing will contribute to the deterioration/ ageing of oil, which causes:

- reduction of lubricating efficiency = greater wear
- reduction of anticorrosion = rust
- “polymerization” = loss of lubricating properties
- increase of acidity = corrosion
- necessity to change the oil = costs

4. **Recommended properties of the lubricant**

The IDEAL lubricant for Rotary Vane compressors must have the following properties:

Ø lowest possible viscosity
Ø highest lubricating power
Ø resistance to high temperatures
Ø detergent and dispersant property
Ø chemical stability
Ø technical-economic benefits

5. **Recommended properties of the lubricant**

Every “desirable” property affects one or more aspect of lubrication:

Ø LOWEST POSSIBLE VISCOSITY

Where the chemical composition is balanced,
the greater the FLUIDITY of the oil, the greater the following properties
=
Energy saving
Easy start-up
Lower wear and tear from Stick-Slip
Greater temperature/thermal exchange
Lower residue and deposits

6. **Recommended properties of the lubricant**

Ø MAXIMUM LUBRICATING POWER

Where viscosity is balanced but chemical composition differs,
the oil may be more or less lubricating
=
Energy saving
Lower wear and tear
Lower maintenance cost and downtime

7. **Recommended properties of the lubricant**

- RESISTANCE AT HIGH TEMPERATURES

Where viscosity and chemical composition are balanced,
the oil may be more or less suitable
for lubrication at high temperatures
=
Lowest loss of viscosity (high VI)
Reduced oxidation of the oil
Reduced formation of acid compounds
Protection of mechanical parts
Long operating life

8. **Recommended properties of the lubricant**

- DETERGENT AND DISPERSANT PROPERTY

This property is either inherent
or is supplied by additives
=
Prevents the agglomeration of sludge
Prevents the formation of coatings
Maintains the whole system in good condition

9. **Recommended properties of the lubricant**

- CHEMICAL STABILITY

Chemical stability accounts for
at least 50% of the “quality” of a lubricant
=
it does not form by-products of decomposition / polymerization
This generic term encompasses all possible alteration/modification which the oil may undergo on account of:
Exposure to high temperature; Contact with oxygen;
Mechanical shearing; Hydrolysis (reaction with water)

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10. **Recommended properties of the lubricant**

- TECHNICAL-ECONOMIC BENEFITS

The balance of Advantages and Costs determines
the Technical-Economic Benefits
=
Cost of the oil per hour/m^3 of air produced
Energy savings (less consumption of electricity)
Reduced wear and tear, longer mechanical life
Reduced time and cost of machine downtime
Less used oil waste to dispose

11. **Analysis of the Lubricant**

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The analysis of the lubricant, when done routinely, is an excellent method for the assessment of:

- suitability of the lubricant for continued use
- the quality of in-take air
- the state of wear in the compressor

MAIN ANALYSES OF THE LUBRICANT

- Viscosity at 40°C and at 100°C
- Viscosity index
- Water content
- Total acidity
- Abrasive metals and silicon dust

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- Oxidation
- Nitration
- Breakdown of esters
- Breakdown of additives

12. **SYNTHETIC LUBRICANTS**

Synthetic lubricants encompass a very wide range:

- Di-esters
- Phosphoric esters
- Methyl silicones
- Chlorinated dyphenil
- Esters of neopenthylpolyoil
- Silicic and di-siloxane esters
- PolyAlkylenGlycols (PAG)
- Fluorinated hydrocarbons

- Polyphenyl esters
- Hydrogenated Hydrocarbons
- PolyInternalOlefin (PIO)
- PolyAlfaOlefin (PAO)
- Alkyls
- PerFluorPolyEsters **OR** Ethers

13. CHEMISTRY OF SYNTHETIC LUBRICANTS
GENERAL STRUCTURE

ESTERS

POLYALFAOLEFIN

POLYGLYCOLS

SILICONS

14. PROPERTIES AND CHARACTERISTICS

Today, lubrication is a scientific matter.
Lubricating oils are defined and catalogued in accordance with:

- their chemical-physical aspect
- their functional aspect
- their tribological aspect. (*attrition and wear)*

All phenomena concerning lubricating oil have been thoroughly studied and standardized.

Bodies such as DIN, SAE, ACEA and ASTM have codified hundreds of tests in order to evaluate the performance of oils in service.

14.b. PROPERTIES AND CHARACTERISTICS

The close study of lubricants has sprung from the large diffusion of:

- endothermic motors
- oleodynamic motors
- powerful gears/transmissions

These 3 categories use 80% of lubricants on the market.
Lubricating oil used in air compressors accounts for about 11% of the World demand – equal to 98,000,000 liters of oil.

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15. TECHNICAL DATA

We list below the principal tests carried out on compressor lubricants:

Class ISO *(viscosity at 40°C)*:

- viscosity at 100°C
- viscosity at ….. °C
- index of viscosity
- relative density
- total acidity
- flash point
- corrosion of metals
- carbon residue
- de-mulsification
- de-aeration
- foaming
- evaporation
- wear
- ignition point
- pour point

16. KINEMATIC VISCOSITY unit of measure: mm²/s (cSt)

KINEMATIC VISCOSITY is the main and best-known characteristic of lubricating oil. The term defines the movement or drag of fluids over a surface.
KINEMATIC VISCOSITY (henceforth ‘viscosity’) is measured with a viscometer.

The viscometer and the oil contained therein are immersed in a fluid kept at a given temperature. The test measures the time that the oil viscosity takes to fall.

The time is measured in seconds and multiplied by a given co-efficient which varies from viscometer to viscometer; the result indicates the viscosity of the oil at the given temperature.

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16b. KINEMATIC VISCOSITY unit of measure: mm²/s (cSt)

The current international classification for industrial oils was perfected by the ISO (International Standard Organisation) as ‘norm ISO 3448’, which established that industrial oils be classified according to KINEMATIC VISCOSITY at 40°C, expressed in mm²/s - equivalent to cSt – an abbreviation for CentiStoke or hundredths of Stoke.

‘Stoke’ is the name of the scientist who created this system of measurement.

Viscosity is influenced by: temperature, impurities in the fluid, by-products of reaction/decomposition, air or gas bubbles.

16c. **KINEMATIC VISCOSITY** unit of measure: mm²/s (cSt)

Stoke based his scale of values upon 1cSt of water at temperature of 20°C.

An average motor oil of 15W40 has about 170/200 cSt at 20°C, that is – 170/200 times the viscosity of water. CSt is a proportional unit: an oil with 10 cSt has 10 times the viscosity of water at 20°C.

The most widely-used and accredited method of measuring viscosity is test 'D445', proposed by the ASTM (American Society for Testing & Material).

Viscosity at temperature 40°C defines the ISO class.

16d. **KINEMATIC VISCOSITY** unit of measure: mm²/s (cSt)

ENGLER degrees (°E) is another unit of measure for viscosity, but it is not as accurate and proportional as cSt and has become obsolete, along with others such as SUS (Saybolt Universal System) and AGMA (for gear oils).

Special tables facilitate conversion from one type of unit to another.

The viscosity of a lubricant needs to be established at the planning stage of a machine, taking into account the factors of temperature, tolerances, speed, load, nature of materials, lubrication system, etc.

17. **VISCOSITY INDEX** unit of measure: natural number

As the temperature rises the viscosity of oil decreases: molecules slide more freely one on the other, therefore resistance decreases.

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Not all oils are equally sensitive to variation in temperature.

To determine the variation in viscosity caused by temperature, viscosity is measured at 40°C and at 100°C. Viscosity at 100°C will be less than that at 40°C, for example:

	cSt at 40°C	cSt at 100°C	Viscosity Index
Oil A:	46	7.20	110
Oil B:	46	8.00	130

17b. **VISCOSITY INDEX** unit of measure: natural number

	cSt at 40°C	cSt at 100°C	Viscosity Index
Oil A:	46	7.20	110
Oil B:	46	8.00	130

The two oils have the same viscosity at 40°C, but at 100°C oil B has greater viscosity than oil A.
It follows that oil B is less sensitive to variations in temperature than oil A.
This +/- variation is known as Viscosity Index (V.I.) and is expressed with a natural number, arrived at by a mathematical formula.
The example above reflects test ASTM D2270 which correlates viscosity of oil at 40°C and at 100°C.
Therefore, oil has a high V.I. when it exhibits a minimal variation in viscosity against the variation of temperature.

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17c. **VISCOSITY INDEX** unit of measure: natural number

Technically, the Viscosity Index can be good or bad, depending on the particular use of the lubricant.
Generally, oil with high V.I. is preferable, but this may not always be the best solution.
The V.I. property of oil may be increased by adding the appropriate POLYMERS, but there is a risk of the following undesirable results:

- loss of lubrication
- formation of sticky coatings
- formation of carbon residue
- loss of V.I. due to mechanical breakdown
- separation/stratification

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17d. **VISCOSITY INDEX** unit of measure: natural number

Therefore oil may have a Viscosity Index that is:

low =	50 - 70	medium =	70 - 100
good =	100 - 150	high =	150 – 200

excellent = > 200

17e. **VISCOSITY INDEX** unit of measure: natural number

The Viscosity Index is influenced by:

- the nature of the lubricant
- the method used to refine/produce it
- its viscosity.

During operation, the Viscosity Index may vary on account of:

- the breakdown of POLYMERS
- evaporation of weak/light components
- dilution/pollution by fluids with a different V.I.
- reaction by polymerization (temperature, impurities)
- hydrolysis (a specific reaction with water)

18. **RELATIVE DENSITY:** unit of measure: g/liter

Relative Density or *“the weight of one liter of fluid”.*

Often the term ‘Specific Weight’ is used but incorrectly, since by definition it applies to solid substances.
Relative Density is expressed in grams/liter or Kg./m³; that is - RELATIVE to the density of water which, conventionally, has a value of 1000g/liter at 20°C.
The appropriate test is DIN 51-757 or ASTM D1298.
There are not many instances where Relative Density is of any great significance in lubrication.
One may state that a conventional Mineral Oil has a relative density of about 900g/liter, while the recommended oil should be about 950g/liter.
The PAOs (PolyAlfaOlefin) are very similar to mineral oil, Silicons have about 1000g/liter and the PAGs (PolyAlkylenGlycols) are 1,000g/liter.
Higher values are to be found in the range of PFPEs (PerFluorPolyEsters **OR** Ethers) which have a relative density in the region of 1,600g/liter.

19. **TOTAL ACIDITY NUMBER (TAN):** unit of measure: mg KOH/g

TAN indicates the quantity of acid groups in the lubricant.
Acid groups are present in every lubricant and they increase with wear.
The standard test is ASTM D664 which uses Potassium Hydroxide (KOH) to neutralize the acid groups in the fluid.
The TAN of fresh oil depends on:

- the chemical composition of the lubricant
- additives.

NB: in the case of Ester oils, the TAN needs to be assessed differently from mineral oils.
Ester oils have a pseudo-acidity due to the structure of their ester molecule and not because of acid impurities.

19b. **TOTAL ACIDITY NUMBER (TAN):** unit of measure: mg KOH/g

During operation the acidity of a mineral oil may reach a maximum of 2 – 3, whereas our 8000 F2 may reach 8 and above in certain cases.

Variation of the TAN during use may vary for the following reasons:

- exposure to high temperatures
- chemical breakdown of the lubricant (mechanical-thermal stress)
- by-products of oxygen reaction (oxidation)
- pollution by other substances.

Technicians use the TAN as a first indication of the integrity of the lubricant.
If the TAN is above maximum the oil has to be changed even if all other values are within spec.
On the other hand if the TAN is good then it is highly unlikely that the other values will be faulty.

20. **DEMULSIFICATION:**
unit of measure: ml of oil to ml water/ml emulsion – in minutes

DEMULSIFICATION is the capacity (in terms of speed and quality) of oil to separate from water. There are various methods of measuring it and the test is ASTM D1401, the most widely used for compressor oils.

In a cylinder place 40cc of oil and 40cc of water.
Water being heavier, it will settle at the bottom.
Place the cylinder inside a bath of water at standard temperature: 54.4°C.
Insert a mechanical agitator into the cylinder and stir the fluid vigorously for 5 minutes.
Then note the time required for the fluid to separate into oil/water.

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20b. **DEMULSIFICATION:**
unit of measure: ml of oil to ml water/ml emulsion – in minutes

De-emulsification is expressed as:
ml of oil /ml of water /ml of emulsion (number of minutes)

20c. **DEMULSIFICATION** unit of measure: ml of oil to ml water/ml emulsion – in minutes

The emulsion is composed of unequal quantities of oil and water and, at times, the sum in ml of oil + water + emulsion is greater than 80, on account of the “greater volume “of the emulsion.
The degree of de-emulsification is of particular interest for motor-, compressor-, turbine- and hydraulic oils since these oils are in contact with humidity.
Normally, for products of the same nature, de-emulsification is inversely proportional to their viscosity, or, the more viscous a product the poorer its separation properties.

It may happen that a new oil has a satisfactory figure of de-emulsification but may not perform to spec during use.
The steady maintenance of de-emulsification depends largely on the stability of oxidation – it decreases as the oil decays.

21. **CARBON RESIDUE** unit of measure: % in weight

The most widely used test for carbon residue is ASTM D189-65 also known as CONRADSON, after the name of its creator.
Carbon residue is the term used for the tendency of non-volatile lubricants to leave residues that contain carbon compound
Mineral lubricants vary greatly with regards to carbon residue and this depends on their hydrocarbon component which may vary in volatility.
In order to compare the carbon residue of different oils it is necessary to use the same method.

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22. **STABILITY OF OXIDATION:** unit of measure: % in weight

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An oil in service is subject to oxidation caused mainly by: the effect of heat, the presence of water and air in the circuit, and the catalytic action of other substances in particular copper and [other] metals.
Oxidation of the oil results in blackening, an acrid/pungent smell, the formation of **sludge** [NB] and the corrosion of metals.
Stability of oxidation depends on the nature of the oil and on the presence of specific anti-oxidants or inhibitors.
Mineral oils without additives keep their properties briefly, then oxidation sets in which slowly increases to the point where the oil needs to be changed.

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22b. **STABILITY OF OXIDATION:** unit of measure: % in weight (loss)

TYPICAL ADDITIVE ~ ANTI-OXIDANT

=

ZINCDIISOPROPYLDITIOPHOSPHATE

An Anti-oxidant reacts with the primary products of oxidation rendering them inert or in other words neutralizing them, thereby considerably lengthening the life of a lubricant.
Synthetic lubricants like PolyAlfaOlefins and Esters have great natural stability toward oxidation.

23. **UNCTUOUSNESS:**

UNCTUOUSNESS is the capacity of oil to adhere to surfaces that glide against each other thereby keeping them apart and coated with a protective film known as 'epilamine'.
In grease-based lubrication the lubricant intervenes between the gliding surfaces in the form of two extremely thin films which adhere tenaciously to the solid surfaces.
These two lubricating films are known as 'epilamines'.

Therefore attrition is limited to the gliding of one epilamine on the other and is far lower than that caused by the direct contact of the two surfaces.

23b. **UNCTUOUSNESS**

UNCTUOUSNESS can be increased with additives. The most common substances are fatty acids which are obtained from vegetable and animal fats. However these can form corrosive compounds.
Unctuous additives are also known as 'accentuators of the resistance of the lubricating film'.
They confer very high tenacity to the lubricating film and strong adhesion to metallic parts.
They are not 'stable' and have no corrosive action on metals.
Unctuous additives adhere to metals by means of two actions:
The first is physical and depends upon the polarity of their molecules towards metal;
in the second, the additives adhere both chemically and physically and their polarity hinges on an acid group that is organic and oil-soluble.

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23c.UNCTUOUSNESS

UNCTUOUS ADDITIVE

MONOOLEATEGLYCERINE

Unctuous additives lose their effectiveness at high temperatures because the polarity of the chemical group loses priority with respect to the solubility in oil of these molecules.
Synthetic Esters lubricants have a natural polarity towards metals (electro-affinity).

24. **ANTI**CORROSION **/ WEAR** unit of measure: mm

EXTREME **P**RESSURES: unit of measure: Kg or Lbs

When pressure on the surfaces is such that the unctuousness of the lubricant is no longer effective, the surfaces come into direct contact with each other and begin to wear.
The additives for anti-wear and extreme pressures (EP) prevent contact of metal on metal as well as seizures and welds.
The test ASTM D4172 is used to evaluate the anti-wear properties of a lubricant.

25. **EXTREME PRESSURES** unit of measure: Kg or Lbs

The condition of 'Extreme Pressures' also known as 'Lubrication Limit' arises when the unctuous properties of a lubricant fail to separate the moving surfaces.
The EP additives react with metals giving rise to inorganic salts with a high fusion point and a low friction coefficient which anchor themselves firmly to metal surfaces.
The formation of inorganic salts kicks in only under high temperatures caused by high attrition: only then are the active elements sulphur, chlorine and phosphorus activated to react with metals.

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25b. **EXTREME PRESSURES** unit of measure: Kg or Lbs

These elements attach to metal by physical action but as the temperature rises they react with metal and form an inorganic salt.
Adherence to metal is then much stronger because these salts have a very low solubility in oil.

Mixed additives 'EP/Unctuous' of the Ester type are widely used since, in normal conditions, they do not contain free-acid groups, but under high temperatures they decompose into an inert substance and an acid which then reacts with metals to form a salt.

25c. **EXTREME PRESSURES** unit of measure: Kg or Lbs

The higher the pressure the greater the necessity to use lubricants with high Unctuous/Anti-wear/EP properties.

26. **ANTI**CORROSION **/ WEAR** unit of measure: mm

EXTREME **P**RESSURES: unit of measure: Kg or Lbs

ANTI-WEAR ADDITIVE

DIBUTYLDITICARBAMATE

The latest EP lubricants contain special substances – phosphorus, sulfur, chlorine, lead - which form a protective film on metal surfaces by chemical reaction.

27. **FOAMING** unit of measure: ml foam /Sequence 1, 2, 3

Like many other liquids, lubricating oils tend to effervesce when mixed with air, especially when the oil is used at very high speed and is forced through an intricate course.
The assimilation of air into oil is inevitable, however much this may be avoided in the planning stage.
The formation of foam can aggravate the transmission of heat and raise temperature.
It can also cause the oil to overflow through the air-vents and interfere with the delicate function of the oleodynamic regulators.

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27b. **FOAMING** unit of measure: ml foam /Sequence 1, 2, 3

Under high temperature, foaming accelerates the process of oxidation since the air in foam contains oxygen.
It is therefore imperative that the oil promptly expel incorporated air.
The test for foaming is ASTM D982 which takes into account the 3 phases of insufflation of air:

Sequence 1: 10°C
Sequence 2: 50°C
Sequence 3: 10°C

27c. **FOAMING** unit of measure: ml foam /Sequence 1, 2, 3

ANTI-FOAMING ADDITIVE

SILICONIC

The use of anti-foaming additives improves the expelling property of oil, but often the action of the additives wears out before the oil has reached end-of-life.

28. **EVAPORATION** unit of measure: % loss of weight

It is important that the % of evaporation be low, especially in oils that lubricate at high temperatures.
The test for evaporation is ASTM D972 which can be carried out at different temperatures depending on the projected use of the oil; generally at 100°C for a period of 22 hours.
In mineral lubricants ~ the greater the viscosity the less the volatility.
In synthetic lubricants volatility is not tied to viscosity. It depends greatly on the type of synthetic: ester, silicon or other.

29. **POUR POINT** unit of measure: °C

The Pour Point is the temperature at which oil flows before it congeals.
It is a very important factor in low temperature applications.

The test is ASTM D97 carried out as follows:

Place a quantity of oil in a glass cylinder and place the cylinder in a refrigeration unit.
Lower the temperature gradually and every 2 degrees remove the glass cylinder and incline it.
If the oil moves, replace the cylinder into the refrigerant and continue lowering the temperature.
The test ends at the degrees at which the oil no longer flows.

29b. **POUR POINT** unit of measure: °C

ADDITIVE: POUR POINT DEPRESSANT

POLYACRYLATE

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Additives with ‘anti-congealing’ properties absorb paraffin crystals as they form at low temperatures and enable the oil to maintain a good pour point.

30. **FLASH POINT / FLAMMABILITY** unit of measure: °C

The term Flash Point indicates the temperature at which the vapors of hot oil catch fire when in contact with a flame.
The test is ASTM D92 in a Cleveland Open Cup.
Test D93 is more stringent in that it measures flash point in a closed vessel – Perkins Martens.
The test is simple: the lubricant is heated in a crucible and brought into contact every 2°C with a small flame until the vapors briefly catch fire (flash).
If the crucible is closed all vapor is retained and flash point will occur at a lower temperature.

31. **COMBUSTION POINT** unit of measure: °C

Proceeding by 2°C beyond flash point, the combustion point is reached when the lubricant catches fire and burns for at least 5 seconds.
The standard test is ASTM D240.

32. AUTO COMBUSTION unit of measure: °C

Auto combustion occurs at the point where oil catches fire spontaneously and burns to extinction, without the aid of flame or spark.
The standard test is ASTM D2155.

33. **DETERGENT AND DISPERSANT PROPERTIES**

Synthetic lubricants have excellent detergent properties, especially the Di-esters which are oils with inherent solvent properties.
Their action is to ‘wash out’ the residue of previous lubricants and release them into the oil filter.

TYPICAL DETERGENT ADDITIVE

METALLIC PHENATE (M=Na, Ca, Ba, Mg, AL, etc)

DISPERSANT: SUCCINATE

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34. **ANTIRUST** anticorrosion test

In the presence of limited moisture, mineral oils have antirust properties.
However when the amount of moisture is above a determined limit and especially when environmental conditions cause alternating condensation and evaporation on metal surfaces, the inherent protective action of the oil is no longer adequate.
This is the case especially in highly refined oils since refinement reduces their 'anti-rust' properties. Anti-rust additives then become indispensable

34B. **ANTIRUST** anticorrosion test

TYPICAL ADDITIVE: ANTI-CORROSION

TRIAZOLE

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