



Professional Bachelor Electromechanics



OIL ANALYSIS AS TOOL FOR PREDICTIVE MAINTENANCE FOR CRYOGENIC COMPRESSORS AT CERN

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The student takes full responsibility for this dissertation. Dissertation supervision and process coaching does not eliminate incomplete information and/or inaccuracies which have been taken into account in the final evaluation, but which have not been modified in the final version of the dissertation.

i. Summary

Title:

Oil analysis as tool for predictive maintenance for cryogenic compressors at CERN

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The subject of this thesis is developing an oil analysis plan to use as a tool for predictive maintenance on compressor systems. This oil analysis plan will be implemented for the compressors that are part of the cryogenic installations at CERN. These installations are used to cool down the helium that flows throughout the LHC and several other experiments at CERN.

The research question of this thesis is: "How can the oil analysis plan of the cryogenics plants at CERN be improved?"

The goal of this thesis is developing an oil analysis plan that will add to and improve the current predictive maintenance plan. This will result in a higher reliability of the compressor systems, which prevents unplanned stand stills that have to be avoided.

The current oil analysis plan for the compressor systems at CERN is only used to check the oil condition to check if the oil needs to be replaced. To use oil analysis as tool for predictive maintenance a completely new plan will have to be developed since the current plan is not thorough enough.

To find a solution the current procedures at CERN and the state of the art practices for the oil analysis have been researched. After which improvements to the current procedures have been searched. The focus is first put upon one of the systems in use at CERN. The oil analysis plan for this system is then applied to the other systems.

The result is a base for the oil analysis plan which can be built on and customised to the requirements of each individual compressor station. This makes it possible to include oil analysis as part of the predictive maintenance at CERN.

ii. Samenvatting

Titel:

Olie analyse als deel van predictief onderhoud voor cryogene compressoren in CERN

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Het onderwerp van deze thesis is het ontwikkelen van een plan voor olie analyse dat zal gebruikt worden als deel van het predictief onderhoudsplan voor compressor-systemen. Dit olie analyse-plan zal ingevoerd worden voor de compressoren die deel uitmaken van de cryogene installaties in CERN. De cryogene installaties worden gebruikt om het helium, dat door de Large Hadron Collider (LHC) en verschillende andere experimenten vloeit, af te koelen.

De onderzoeksvraag van deze thesis is: "Hoe kan het huidig onontwikkeld olie analyse-plan voor de cryogene installaties in CERN verbeterd worden?"

Het doel van deze thesis is een olie analyse-plan ontwikkelen dat toelaat om predictief onderhoud te implementeren voor de compressor-systemen. Dit zal leiden tot een hogere betrouwbaarheid van deze systemen door problemen met de compressoren te voorkomen.

In het huidig olie analyse-plan voor de compressoren in CERN wordt enkel de conditie van de olie onderzocht om te bevestigen of deze moet worden vervangen. Om olie analyse als deel van predictief onderhoud te gebruiken, moeten echter aanpassingen en verbeteringen aangebracht worden omdat het oorspronkelijk plan niet grondig genoeg is.

Om een oplossing te vinden, zijn de originele procedures die worden gebruikt en de verschillende types van compressor-systemen in CERN, alsook de state of the art toepassingen van olie analyse onderzocht. Vervolgens is een olie analyse-plan opgesteld voor één van de systemen. Dit plan zal dan aangepast en uitgevoerd worden voor de andere compressor stations.

Het resultaat is de basis van een olie analyse-plan waarop kan worden verder gebouwd en dat vervolgens kan aangepast worden naar de specifieke eisen van elk compressor station. Dit maakt het mogelijk om olie analyse te gebruiken als deel van het predictief onderhoudsplan in CERN.

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iv. Table of contents

i.	Summary	3
ii.	Samenvatting.....	4
iii.	Acknowledgements	5
iv.	Table of contents.....	7
v.	List of abbreviations.....	9
vi.	List of figures	10
vii.	List of tables	12
1.	Introduction	1
1.1.	Introduction to CERN	1
1.2.	Introduction to the LHC Project.....	1
1.3.	Introduction to TE/CRG/ME.....	2
1.3.1.	Technology (TE) department	2
1.3.2.	Cryogenics (CRG) group	2
1.3.3.	Mechanical and Engineering support (ME).....	2
1.4.	Introduction to the Bachelors thesis.....	3
2.	Introduction to oil analysis.....	4
2.1.	Goals of oil analysis	4
2.1.1.	Oil condition.....	4
2.1.2.	Contamination.....	5
2.1.3.	Machine condition.....	6
2.2.	Oil analysis methods	7
2.2.1.	Inductively Coupled Plasma (ICP) Spectroscopy ASTM D5185	7
2.2.2.	Fourier Transform Infrared (FTIR) Spectroscopy ASTM E2412	8
2.2.3.	Particle Quantification (PQ) index using analex PQA	10
2.2.4.	Viscosity (40°C, 100°C) and viscosity index using ISL Houillon Viscometer	11
2.2.5.	Water content according to Karl Fischer	13
2.2.6.	Acid Number (AN) ASTM D664	15
2.2.7.	Particle counting	16
2.2.8.	Analytical Ferrography.....	20
2.3.	Periodicity and position	25
2.2.9.	Periodicity	25
2.2.10.	Position	26

3.	CERN cryogenic installations and oil analysis.....	27
3.1.	Introduction to a cryogenic installation	27
3.1.1.	Terminology of the compressor stations	29
3.2.	General inventory of compressor stations at CERN	30
3.2.1.	System 1A	30
3.2.2.	System 2.....	31
3.3.	Screw- vs Piston compressor	32
3.4.	Current oil analysis practices at CERN.....	33
4.	Applying oil analysis to Kaeser HSDV760 compressor	34
4.1.	Kaeser HSDV760 compressor	34
4.2.	Cognis Breox B35 Oil	36
4.3.	Review of sampling spot.....	37
4.4.	Setting the test slate	38
4.5.	External or internal oil analysis.....	39
4.6.	Writing new sampling procedure	40
4.7.	Setting thresholds and classes for key parameters	41
4.7.1.	Thresholds.....	41
4.7.2.	Class of impact	41
4.8.	Trending of results	42
4.9.	Decision tree.....	43
4.9.1.	Category “Nominal”	43
4.9.2.	Category “Issue”	43
4.9.3.	Category “Major Issue”	44
5.	Conclusion.....	45
viii.	Bibliography.....	46
ix.	Appendix	50

v. List of abbreviations

CERN	European Centre for Nuclear Research (English) Organisation Européenne pour la Recherche Nucléaire (French)
LHC	Large Hadron Collider
TE	Technology
CRG	Cryogenics
ME	Mechanical and engineering support
AN	Acid Number
BN	Base Number
ICP-Spectroscopy	Inductively Coupled Plasma Spectroscopy
FTIR	Fourier Transform Infrared
PQ	Particle Quantification
cSt	centistoke
cP	centipoise
NbTi	Niobium-Titanium
Tc	Critical Temperature
P&ID	Piping and Instrumentation Diagram
WO	Work Order
OB	Observation
PC	Preventive Action (English) Preventif Conditionnel (French)
CA	Corrective Action (English) Correctif Amelioration (French)

vi. List of figures

Figure 1 Particle accelerators at CERN.....	1
Figure 2 Example of oil condition in analysis report [2].....	4
Figure 3 Example of wear and contamination in analysis report [2]	5
Figure 4 Example of particle counting in analysis report [2].....	5
Figure 5 Example of fatigue chunk particle [3].....	6
Figure 6 Wear metals [2].....	6
Figure 7 ICP spectroscopy principle [4].....	7
Figure 8 Colour spectrum of Si, S, Fe, Al [6]	7
Figure 9 Block diagram of an FTIR spectrometer [9]	8
Figure 10 Schematic of the Michelson Interferometer	9
Figure 11 Typical used Oil FTIR spectrum [8]	9
Figure 12 Analex PQA Ferrous Debris Monitor	10
Figure 13 Schematic of PQ magnet assembly [11]	10
Figure 14 Viscosity of different liquids [13]	11
Figure 15 Viscosity index graph [16].....	11
Figure 16 VH1 and VH2 - Houillon viscometer	12
Figure 17 Volumetric titrator [22]	13
Figure 18 Titration cell coulometric titration [22]	14
Figure 19 Coulometric titrator [23]	14
Figure 20 AN test Titrator [26]	16
Figure 21 Example ISO cleanliness class [27]	17
Figure 22 Microscope and sample [29].....	17
Figure 23 Light blockage particle counter [30].....	18
Figure 24 Light scattering particle counter [30]	18
Figure 25 Irregular particle.....	19
Figure 26 Pore blockage particle counter	19
Figure 27 Ferrogram slide maker [33]	20
Figure 28 Aluminium particle on ferrogram [34]	21
Figure 29 Copper particle on ferrogram [35]	21
Figure 30 Babbitt particle on ferrogram [36]	21
Figure 31 Silicon on ferrogram [37].....	22
Figure 32 Cotton fibre under microscope	22
Figure 33 High alloy (grey) and low alloy (blue/purple) steel on ferrogram [38]	22
Figure 34 Dark Metallic oxides on ferrogram [38].....	23
Figure 35 Cast iron particle (yellow) on ferrogram [39]	23
Figure 36 Red oxides on ferrogram [38]	23
Figure 37 Rubbing wear [38]	24
Figure 38 Spherical particles [38]	24
Figure 39 Cutting wear particles [38]	24
Figure 40 Sliding particle [38].....	24
Figure 41 Laminar particle [38]	24

Figure 42 Scuffing particle [49]	24
Figure 43 Monthly vs quarterly sampling	25
Figure 44 Example sampling spots [41]	26
Figure 45 Oil sample taken in a bend [42]	26
Figure 46 CERN cryogenic systems [44]	27
Figure 47 Cryogenic plants and points.....	28
Figure 48 Typical LHC even point [45]	28
Figure 49 Position of QSCCB-18-CO1.....	29
Figure 50 Position of QSCA-6-CO6.....	29
Figure 51 Principle of System 1A	30
Figure 52 Principle of system 2.....	31
Figure 53 Screw compressor [47]	32
Figure 54 Comparison of duty cycles [47]	32
Figure 55 History oil analysis at CERN.....	33
Figure 56 PID of Kaeser HSDV760 [48]	35
Figure 57 Complete system HSDV 760 Point 1.8.....	36
Figure 58 Valve at compressor outlet.....	37
Figure 59 Particle counting old spot	37
Figure 60 Particle counting new spot	37
Figure 61 OSA4 Microlab® from Spectro Scientific	39
Figure 62 Trending Iron QSCB-18 Oelcheck laboratory	42

vii. List of tables

Table 1 Commonly found elements in oil [7]	8
Table 2 ISO cleanliness code [27]	16
Table 3 Recommended sampling frequency [40]	25
Table 4 Commonly used tests and their utility [49]	38

1. Introduction

1.1. Introduction to CERN

CERN, the European Organization for Nuclear Research, is an intergovernmental organization with 20 Member States.

Its seat is in Geneva but its premises are located on both sides of the French-Swiss border.

CERN's mission is to enable international collaboration in the field of high-energy particle physics research and to this end it designs, builds and operates particle accelerators and the associated experimental areas. At present more than 10 000 scientific users from research institutes all over the world are using CERN's installations for their experiments.

The accelerator-complex at CERN is a succession of machines with increasingly higher energies. Each machine injects the beam into the next one, which takes over to bring the beam to an even higher energy, and so on. The flagship of this complex is the Large Hadron Collider (LHC) as presented below (Figure 1):

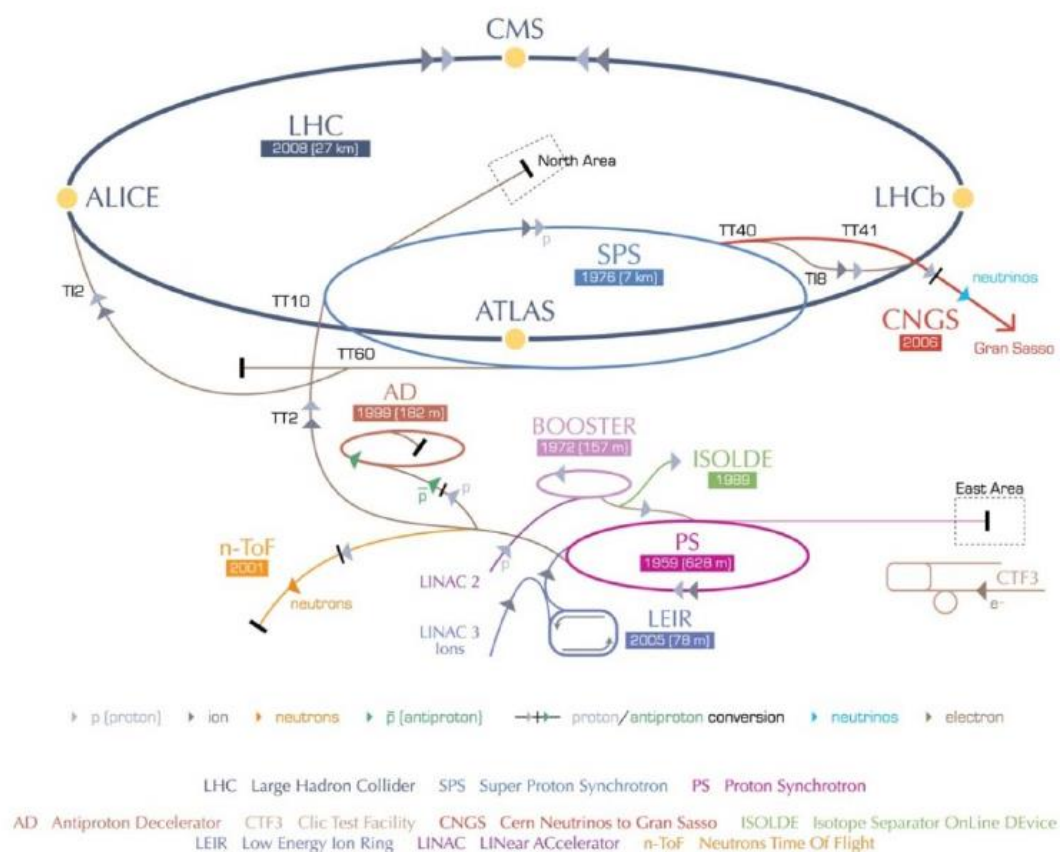


Figure 1| Particle accelerators at CERN

1.2. Introduction to the LHC Project

The Large Hadron Collider (LHC) is the most recent accelerator constructed on the CERN site. The LHC machine accelerates and collides proton beams but also heavier ions up to lead. It is installed in a 27 km circumference tunnel, about 100 m underground. The LHC design is based on superconducting twin-aperture cryo-magnets which operate in a superfluid helium bath at 1.9 K.

1.3. Introduction to TE/CRG/ME

1.3.1. Technology (TE) department

The Technology (TE) department at CERN is responsible for technologies which are specific to existing particle accelerators, facilities and future projects.

Their main domains of activities cover: magnets (superconducting, normal conducting, fast pulsed magnets, electrostatic and magnetic septa), their machine integration and protection, power converters, cryogenics, high and ultra-high vacuum systems, coatings and surface treatments.

1.3.2. Cryogenics (CRG) group

The cryogenics (CRG) group is responsible of the design, construction, operation & maintenance of cryogenics systems for accelerators and detectors.

Their main activities include:

- Design, construction, commissioning, operation and maintenance of the cryogenic systems for CERN accelerators and detectors
- Operation, maintenance and upgrades of cryogenic test facilities
- Support for low-temperature development and test at the Central Cryogenic Laboratory
- Supply of cryogenic fluids on the CERN site
- Consultancy and support in cryogenic design and cryogenic instrumentation.

1.3.3. Mechanical and Engineering support (ME)

The Mechanical and engineering support (ME) section, led by Olivier Pirotte, is responsible for the following activities:

- Mechanical support for the cryogenic equipments of accelerators, detectors, test areas and Cryolab.
- Engineering: Study, definition, procurement and installation of cryogenic equipment.
- Maintenance of mechanical equipment; Supervision of associated maintenance activities; Definition of spares & critical analysis and update of the maintenance plan.

1.4. Introduction to the Bachelors thesis

Nowadays, a lot of companies already use oil analysis as a part of their maintenance activities. The problem is that a majority of the time, nothing is done with the information gained from the oil analysis reports or the analysis plan is not thorough enough to notice an imminent failure. The latter is the problem with the cryogenics compressor systems at CERN.

This thesis will answer the following research question: “How can the oil analysis plan of the cryogenics plants at CERN be improved?”

The answer to this question will be found by:

- Making an inventory of the oil sample procedures, respecting the different installations;
- Drawing up a plan of the relevant oil analyses that would be worth to be implemented for the CERN installations according to the state of the art of (predictive) maintenance.
- In the plan, the location where the samples are collected, their frequency, what shall be analysed (chemical content, particles, ...) will be considered.

The expectation of this thesis is that the compressor-stations of the cryoplants at CERN will have a fully functional oil analysis plan. This plan will be implemented and improve the current predictive maintenance plan.

2. Introduction to oil analysis

2.1. Goals of oil analysis

The information in this section can be found in '*O&M Best Practices Guide*':

There are three main goals in oil analysis:

- Checking the oil condition [1];
- Checking for contamination [1];
- Checking the machine condition [1].

2.1.1. Oil condition

Oil condition, as the name states, is used to monitor the condition of the oil. This indicates if the current condition of the oil will be able to lubricate the system as per design. This way you can determine if the oil needs to be changed or not. Tests are performed to determine the lubricant viscosity, acidity, colour, etc., as well as a chemical analysis to check the condition of the oil additives [1].

The most commonly used test to determine oil condition are:

- Viscosity [1];
- Acid number (AN) [1];
- Base number (BN) [1].

Other tests such as a chemical spectroscopy can also be used to determine the presence and effectiveness of the oil additives [1].

An example of the checked characteristics can be found in Figure 2.

OIL CONDITION		
Viscosity at 40°C		mm ² /s
Viscosity at 100°C		mm ² /s
Viscosity index		-
Oxidation		A/cm
Color		Color index
ADDITIVES		
Calcium	Ca	mg/kg
Magnesium	Mg	mg/kg
Boron	B	mg/kg
Zinc	Zn	mg/kg
Phosphorus	P	mg/kg
Barium	Ba	mg/kg
Sulphur	S	mg/kg

Figure 2 | Example of oil condition in analysis report [2]

2.1.2. Contamination

To check for contamination of the lubricant, you determine if any physical boundaries have been violated [1]. A violation may cause the lubricant to deteriorate or lose its lubricating properties. To check the lubricant for contamination the following properties are checked (See Figure 3).

CONTAMINATION		
Silicon	Si	mg/kg
Potassium	K	mg/kg
Sodium	Na	mg/kg
Tungsten	W	mg/kg
Water K. F.	ppm	

Figure 3 | Example of wear and contamination in analysis report [2]

An additional way to check the oil contamination is by doing a particle counting. This is used to check the ISO cleanliness class of the oil, which indicates whether the oil is contaminated or not [1].

Figure 4 shows an example of a particle counting in an oil analysis report.

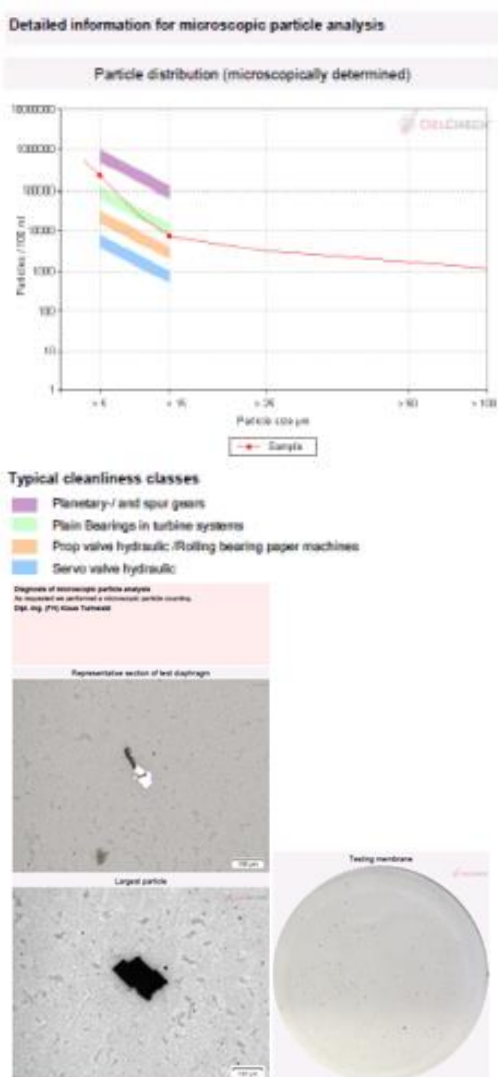


Figure 4 | Example of particle counting in analysis report [2]

2.1.3. Machine condition

Machine condition monitoring is used to determine the machine health. Using this, you can check the machine for wear to predict a failure that is about to occur. This is done by analysing wear particles found in the oil as shown in Figure 5 and checking the chemical elements [1].

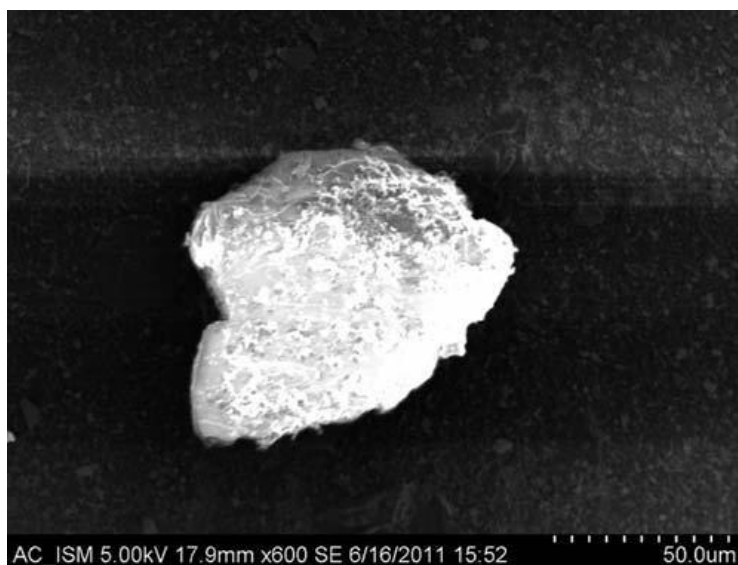


Figure 5 | Example of fatigue chunk particle [3]

Component wear can be determined by measuring the amount of wear metals such as iron, copper, chromium, aluminium, lead, tin and nickel as seen in Figure 6. “An increase in wear metals can mean a particular part of the system is wearing, or wear is taking place in a particular part of the machine” [1].

WEAR		
Iron	Fe	mg/kg
Chrome	Cr	mg/kg
Tin	Sn	mg/kg
Aluminum	Al	mg/kg
Nickel	Ni	mg/kg
Copper	Cu	mg/kg
Lead	Pb	mg/kg
Molybdenum	Mo	mg/kg
Manganese	Mn	mg/kg
PQ index	-	

Figure 6 | Wear metals [2]

2.2. Oil analysis methods

There are many different oil analysis methods available to check both the oil- and machine condition. This is done by doing several tests on the oil. Each of them check for different characteristics of the lubricant. Some of them are a must to give a sufficient amount of information to take action, others are unnecessary and only used in very specific cases.

2.2.1. Inductively Coupled Plasma (ICP) Spectroscopy ASTM D5185

The following information can be found in “Inductively Coupled Plasma Atomic Emission Spectroscopy” [4]

ICP Spectroscopy is used for the detection of metals in the oil. It uses a radiofrequency-induced argon plasma in which a mist of oil is nebulized. This mist gets vaporized and energized through excitation at high temperature. The chemical elements passing through the plasma emit a characteristic light as you can see in Figure 7. Different elements produce different frequencies or colours [5], this way the different chemical elements that are in the oil can be identified. The colour spectra of silicon, sulphur, iron and aluminium can be seen in Figure 8.

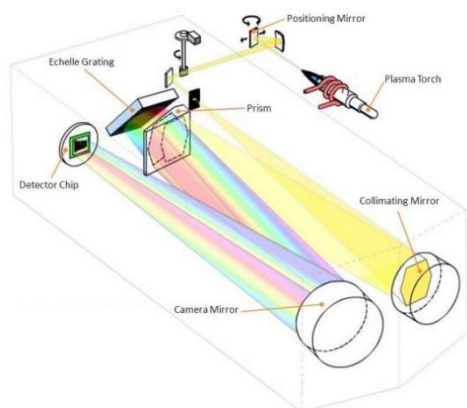


Figure 7 | ICP spectroscopy principle [4]

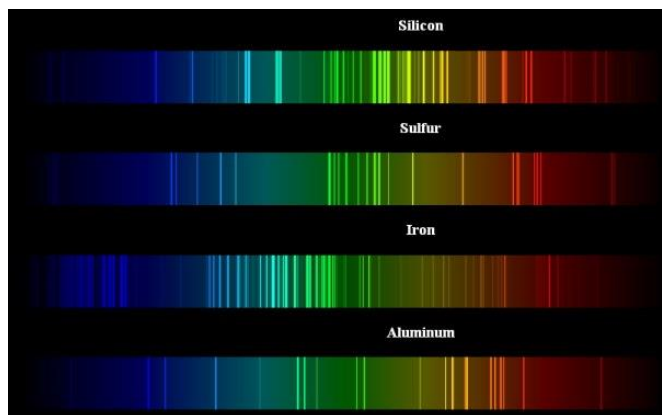


Figure 8 | Colour spectrum of Si, S, Fe, Al [6]

The elements are divided in three broad categories on the reports:

- Wear metals (Fe, Cu, ...)
- Contaminants (Si, K, Na)
- Oil additives (Zn, P, S, ...)

Elements can belong to more than one category. Silicon can indicate wear in pistons or as a contaminant (dirt). The source of a particular element can only be indicated by looking at the complete oil analysis report. [5]

Item	Element	Symbol	Wear	Contam	Additive
1	Iron	(Fe)	x	x	
2	Copper	(Cu)	x	x	x
3	Chromium	(Cr)	x		
4	Tin	(Sn)	x		
5	Aluminum	(Al)	x	x	
6	Lead	(Pb)	x		
7	Silicon	(Si)		x	x
8	Sodium	(Na)		x	x
10	Boron	(B)		x	x
11	Calcium	(Ca)		x	x
12	Magnesium	(Mg)		x	x
13	Zinc	(Zn)	x		x
14	Phosphorous	(P)		x	x
15	Molybdenum	(Mo)			x
16	Potassium	(K)		x	

Table 1 | Commonly found elements in oil [7]

Though ICP spectroscopy is a very important and useful oil analysis test, it has a drawback. The most important limitation is that it cannot vaporize particles with a size greater than 5-8 μm .

This should not cause any problems most of the time, but in some cases the particles could be bigger. This test will not detect these larger particles, which might make the results not representative of the current condition of both the machine and oil condition [5].

2.2.2. Fourier Transform Infrared (FTIR) Spectroscopy ASTM E2412

2.2.2.1. Introduction to FTIR Spectroscopy

The following information can be found in 'Fourier Transform Infrared Spectroscopy':

The FTIR (Fourier Transform Infrared) spectroscopy is one of the most widely used tests in the oil analysis laboratories. This is because it's purely instrument based (meaning it doesn't need extensive sample preparation), it's very quick and it can detect multiple parameters at the same time. These parameters include water, fuel, soot and certain additives. [8]

2.2.2.2. Test setup FTIR Spectroscopy

"A common FTIR spectrometer consists of a source, interferometer, sample compartment, detector, amplifier, A/D convertor and a computer. The source generates radiation which passes the sample through the interferometer and reaches the detector. Then the signal is amplified and converted to digital signal by the amplifier and analogue-to-digital converter, respectively. Eventually, the signal is transferred to a computer in which the Fourier transform is carried out." [9]

A block diagram of an FTIR spectrometer can be found in Figure 9.

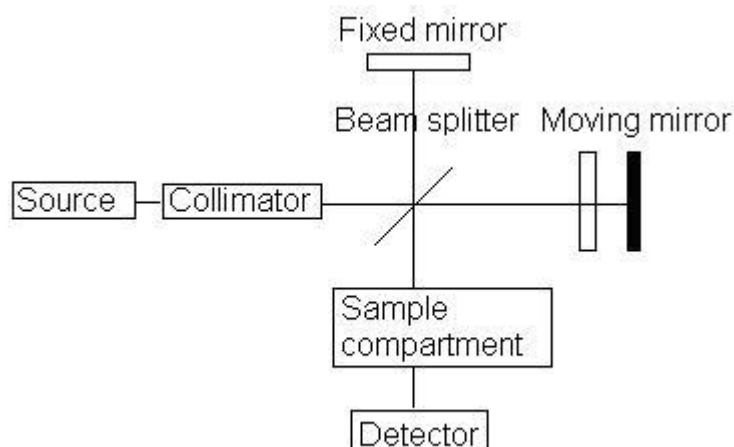


Figure 9 | Block diagram of an FTIR spectrometer [9]

2.2.2.3. Michelson Interferometer

“The Michelson interferometer, which is the core of FTIR spectrometers, is used to split one beam of light into two so that the paths of the two beams are different. Then the Michelson interferometer recombines the two beams and conducts them into the detector where the difference of the intensity of these two beams are measured as a function of the difference of the paths.”

A schematic of the Michelson Interferometer can be found in Figure 10.

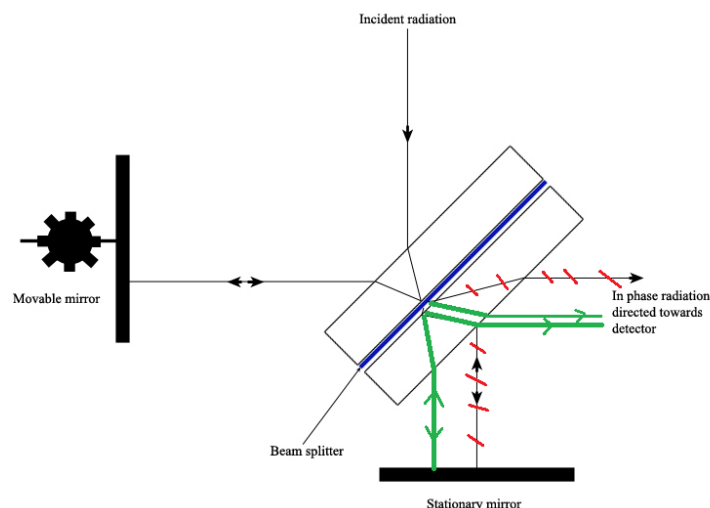


Figure 10| Schematic of the Michelson Interferometer

2.2.2.4. Working principle FTIR Spectroscopy

“The basic principle behind molecular spectroscopy is that specific molecules absorb light energy at specific wavelengths, known as their resonance frequencies. For example, the water molecule resonates around the 3450 wavenumber (given the symbol cm^{-1}), in the infrared region of the electromagnetic spectrum.” [8]

The following information can be found in ‘Fourier Transform Infrared Spectroscopy’:

An FTIR spectrometer works by introducing a small amount of the used oil into the infrared cell. Here an infrared light source is introduced, which is scanned from 4000 cm^{-1} to 600 cm^{-1} . The intensity of the light that passes through the sample is then measured at each wavenumber which indicates the amount of infrared light absorbed by the sample by calculating the difference between the intensity of the light before and after the sample cell. This is called the infrared spectrum of the sample. Figure 11 shows the typical FTIR spectrum of a used oil. [8]

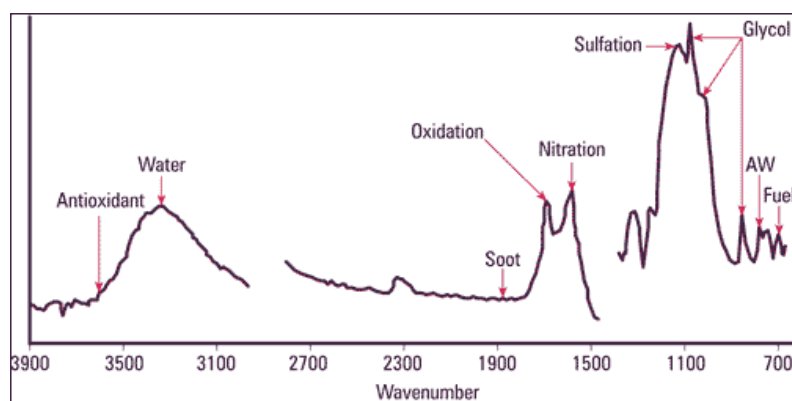


Figure 11 | Typical used Oil FTIR spectrum [8]

2.2.3. Particle Quantification (PQ) index using analex PQA

The PQ index is the mass of ferrous wear debris in an oil sample. This is done making use of a sensitive magnetometer (Figure 12) that measures the mass of ferrous wear debris in the oil sample. [10] The result is then displayed as a PQ index (unit less number). [10]



Figure 12| Analex PQA Ferrous Debris Monitor

The sample is put into the system after it has been put upside down for a certain time, allowing the debris to settle in the cap of the bottle. The system contains 2 magnetic coils that are balanced when no sample is on the sensor. [11] When a sample is placed on the sensor this balance is altered by the ferromagnetic debris. [11] This out-of-balance signal is amplified, filtered and finally displayed as the PQ index of the sample. [11] Figure 13 displays the schematic of the PQ magnet.

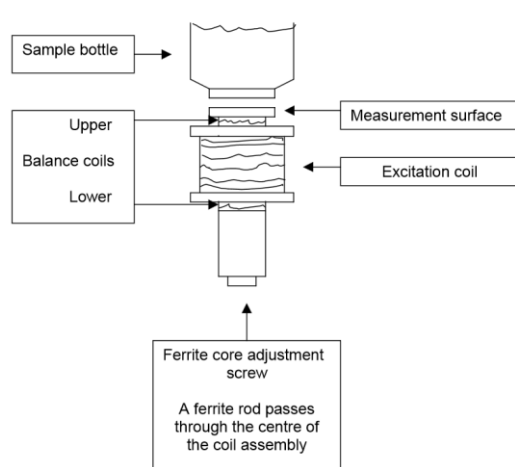


Figure 13| Schematic of PQ magnet assembly [11]

The results of the PQ measurements can then be compared to the amount of iron found in the ICP spectroscopy, since the spectroscopy cannot measure particles greater than 5-8 μm .

3 scenarios are possible:

- High Iron, Low PQ \rightarrow small particles [11]
- Iron \approx PQ \rightarrow small-medium particles [11]
- Low iron, High PQ \rightarrow large particles [11].

A trending of the PQ index is used as a measure of wear condition in systems. The main advantage in using PQ over an ICP spectroscopy is that, unlike with an ICP spectroscopy, particles greater than 5-10 μm can be measured. It is also a very low cost and easy to use solution. [11]

2.2.4. Viscosity (40°C, 100°C) and viscosity index using ISL Houillon Viscometer

2.2.4.1. Viscosity ASTM D7279

The viscosity of oil is its resistance to gradual deformation by shear stress or tensile stress. Informally, it is the 'thickness' of a fluid or its resistance to flow. [12] Ketchup has a much higher viscosity than water for example as seen in Figure 14.

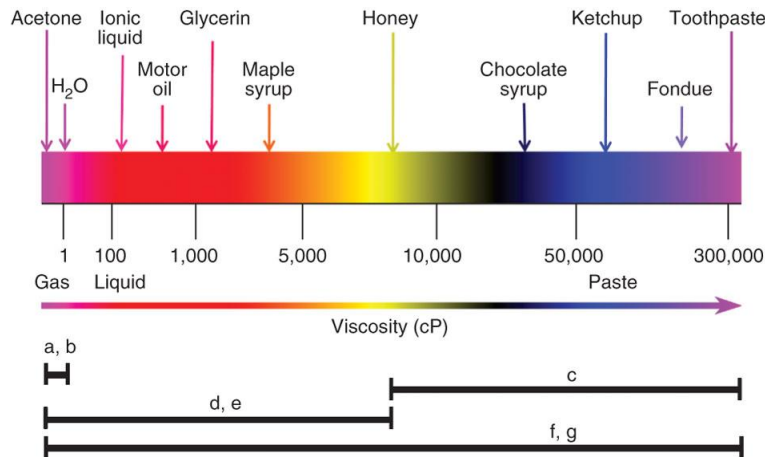


Figure 14| Viscosity of different liquids [13]

The viscosity of an oil is measured in centistoke (cSt) for the kinematic viscosity or centipoise (cP) for the dynamic viscosity. Oil analysis concerns itself almost exclusively with the kinematic viscosity. [14] The viscosity of a fluid always has to be related to a certain temperature as the value changes with temperature. [14] Most of the time a temperature of 40°C or 100°C is used. The higher the value of the viscosity, the thicker the liquid.

2.2.4.2. Viscosity index ASTM D2270

The viscosity index of a fluid is the change of viscosity with variations in temperature. [15] A lubricant's viscosity will change with the temperature. [15] The higher the temperature is, the lower the viscosity or the more fluid the lubricant. [15] Many applications require its oil to perform in a wide variety of temperatures. [15] In these cases an oil with a high viscosity index is chosen. A lubricant with a viscosity index of 110 will be more resistant to temperature than a lubricant with a viscosity index of 35 as seen in Figure 15.

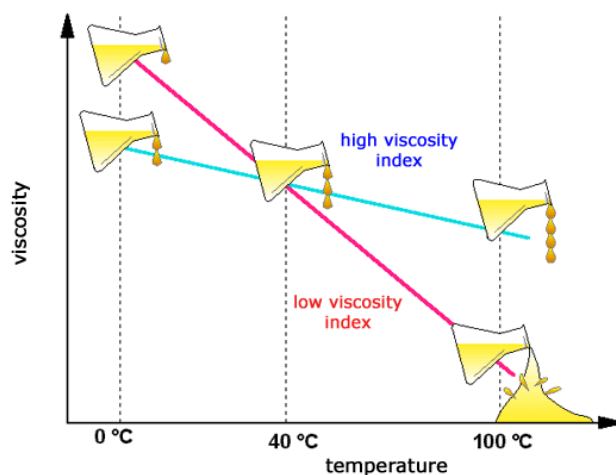


Figure 15| Viscosity index graph [16]

2.2.4.3. ISL Houillon Viscometer

The ISL Houillon viscometer (Figure 16) is a system to automatically determine the kinematic viscosity of oils. [17] A system like this is used because it is faster than normal tests and up to 16 samples can be tested at a time. [17] It also has an integrated cleaning system that makes it very user friendly. [17]



Figure 16| VH1 and VH2 - Houillon viscometer

The testing method goes as follows:

“The sample is injected and then flows into the tube. During the flow phase, the sample comes to the temperature of the Viscometer bath. When it passes in front of the first detection cell, timing is triggered. When it passes in front of the second cell, timing is stopped. The time thus determined allows the software to calculate the viscosity using a constant called the tube constant. This constant is determined by calibration.” [18]

2.2.5. Water content according to Karl Fischer

The following information can be found in 'A closer look at Karl Fischer Coulometric Titration': Karl Fischer titration is a chemical titration method used to determine the amount of water in the sample. There are two types of this test available: volumetric and coulometric titration. The main difference between the two is that with volumetric titration, the titrant is added directly to the sample with a burette. In the coulometric method however, the titrant gets generated in a titration cell electrochemically. Overall, the coulometric method is far more accurate. [19]

2.2.5.1. Volumetric titration ASTM D3401

Volumetric Karl Fischer titration is the most basic version of the test. Water in the sample is detected using a titrant, solvent and the sample itself. The solvent is placed in a sealed container with an electrode called the titration cell. [20] The sample is then dissolved in the solvent, which changes the electrical conductivity of the solvent/ sample mix. [20] An automated burette now adds the titrant, containing iodine (I_2). [20] The amount of water in the sample can then be calculated. [20] This depends on how much of the titrant is needed to return the electrical conductivity to the starting point. [20] An image of the test setup can be found in Figure 17.

This method is used for samples that contain a large amount of water, ranging between 0.1% and 100%. [21]

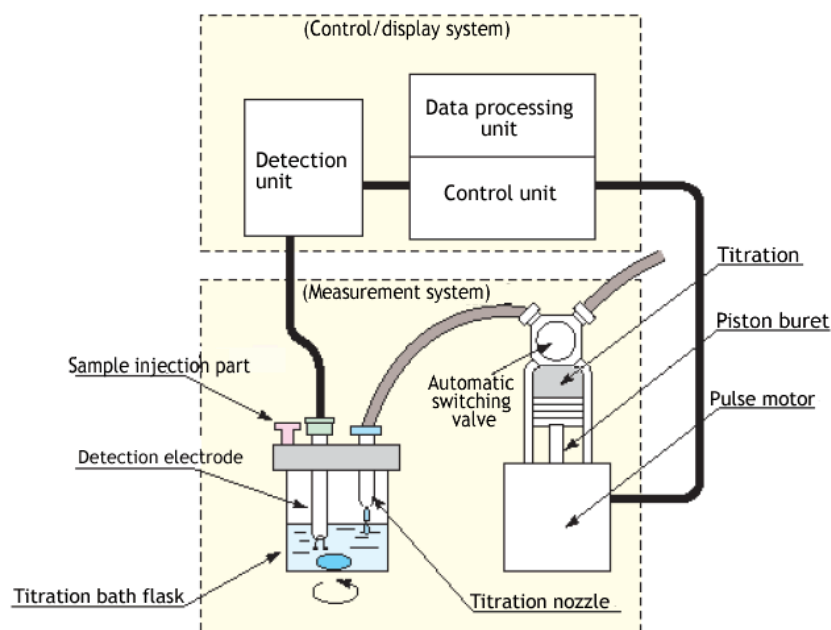


Figure 17| Volumetric titrator [22]

2.2.5.2. Coulometric titration ASTM D6304

The following information can be found in 'A closer Look at Karl Fischer Coulometric Titration': In the coulometric method, the titration cell consists of an anodic compartment and a cathodic compartment. The anodic compartment contains an anolyte solution, made from sulphur dioxide (SO_2), iodide (I^-) and imidazole, which is needed to start the chemical reaction. The two compartments are separated by a ceramic diaphragm. For the solvent methanol or ethanol (ROH , R being an alkyl group) is usually utilised. [19] Figure 18 shows the test setup of a coulometric titration.

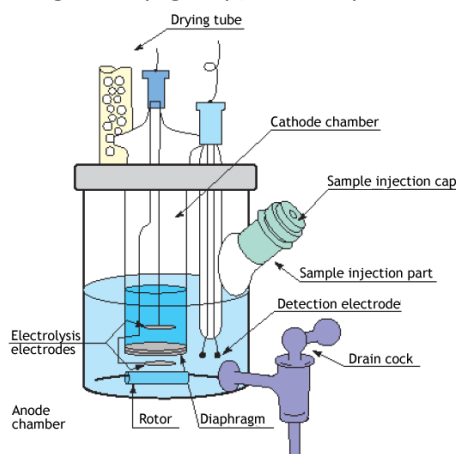
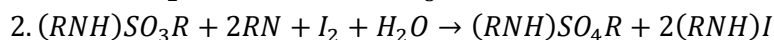


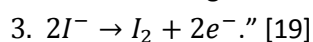
Figure 18| Titration cell coulometric titration [22]

Iodine (I_2) is generated electrochemically from the iodide (I^-) in the anolyte solution. When the water in the sample is mixed with the generated iodine, it gets titrated according to the following reaction scheme:



The reaction stops when all the water has reacted with the iodine. [19]

"The amount of water in the sample is calculated by measuring the current needed for the electrochemical generation of iodine (I_2) from iodide (I^-) according to the following reaction:



A Karl Fischer coulometric titration is one of the most accurate tests available to determine water contamination. Unlike other tests (like crackle), it can detect free, emulsified and dissolved water in the sample. This test can measure water levels up to 0.0001%. [19] A commonly used coulometric titrator can be seen in Figure 19.



Figure 19| Coulometric titrator [23]

2.2.6. Acid Number (AN) ASTM D664

The information in this section can be found in “A Comprehensive Look At the Acid Number Test”:

“Additive depletion, contamination and oxidation are common pathways of lubricant degradation. The acid number (AN) test is one of the methods available in the oil analysis field used to estimate the amount of additive depletion, acidic contamination and oxidation. AN does not directly measure the rate of oxidation, it merely measures the by-product of oxidation. It is also beneficial to trend AN to determine the rate of depletion of certain additives.” [24]

2.2.6.1. Objectives of measuring AN

“When machine lubrication oils oxidize (age), small amounts of acidic by-products form, causing an increase in the amount of acid that is reflected in the lubricant’s Acid Number (AN). AN, sometimes referred to as Total Acid Number (TAN), is a measure of the total acid concentration of the oil. It is expressed as the volume (milligrams) of potassium hydroxide (KOH) required to neutralize acids present in a one-gram lubricant sample.” [25] A number of sources (Acidic contaminants, wrong oil, alkaline-reserve depletion, oxidation by-products, ...) can cause a change in the acid number.

Table 3 shows some common acids that can be detected using AN tests. [24]

Acid Type	Source	Lube Application
Organic (1)	Oil oxidation product	All severe lubrication environments
Hydrochloric (2)	Freon refrigerant breakdown	Chillers
Hydrofluoric (2)	Freon refrigerant breakdown	Chillers
Sulfuric (3)	Diesel fuel and water H ₂ S contamination AW and EP breakdown	Diesel engines NG compressors Hydraulic systems
Nitric (4)	Nitration and nitric oxides	Gas engines Gasoline engines
Phosphoric (5)	Phosphate ester degradation by-products Phosphate mine environment	Mobile equipment, especially hydraulics
Confirming tests: (1) FTIR oxidation (2) Vacuous thinning (3) FTIR sulfation (4) FTIR nitration (5) Elemental analysis - phosphorus		

Table 2 | AN may Detect These Corrosive Oils [24]

Knowing which additives there are in the used oil and the extent of additive depletion is key to determine the Remaining useful life of the oil. [24] Some additives are weakly acidic and can slightly increase the AN at the start of its use. As the oil ages, those additives can deplete and therefore decrease the AN. [24] If the common antiwear additive, Zinc Diakyl Dithiophosphate (ZDDP), produces a certain AN decrease due to the lubricant aging and meanwhile the oil could be contaminated with acidic constituents, which increase the AN. [24] The combined effect of the additive depletion and acidic contamination can make it hard to check what a change in the AN represents. [24]

2.2.6.2. pH vs. AN

“The pH and AN test methods measure different aspects of the oil’s acidic or alkaline character. The pH test method measures the apparent pH of the oil.” [24] This is a representation of how acidic the lubricant is, however it says nothing about the concentration of acidic or alkaline constituents. [24] The pH test is useful where a highly corrosive acid can cause considerable damage to the machine and when there is a high chance for strong acids to form. [24]

2.2.6.3. Working principle of Acid Number ASTM D664 test

ASTM D664 is one of two of the most commonly used and standardised tests to determine the AN of a lubricant. This is done using a titrator as seen in Figure 20.

“ASTM D664 measures acidic constituents by using a potentiometer to determine an end point. This method can be used to measure both AN and SAN. To prepare the sample a mixture of toluene, isopropyl alcohol and water is dissolved into a sample. Potassium hydroxide is then titrated into the solution using a burette. The potentiometer output is monitored while the KOH is titrated into the solution. If the inflection is indistinguishable, the buffer potential will be considered the AN.” [24]

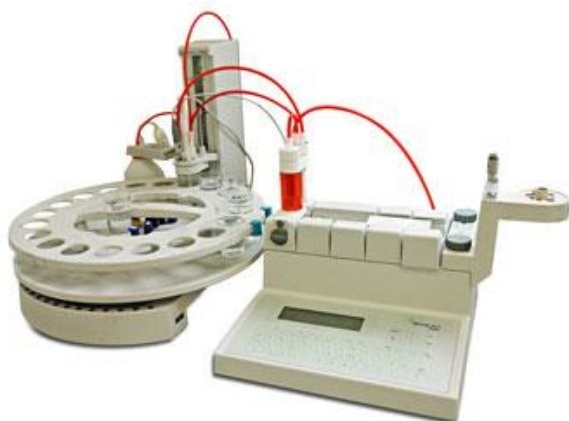


Figure 20| AN test Titrator [26]

To improve the throughput, reduce the cost and decrease the use of hazardous materials this test is often modified by oil analysis laboratories. [24] This does not decrease the quality of the test. [24] It does however makes it hard to compare results of two different laboratories, because of differences in the test’s procedures. [24]

2.2.7. Particle counting

Having clean oil is very important to keep a machine healthy. Particle counting, according to many experts, is the most important test to check the cleanliness of the oil. A great amount of problems can be detected just by carrying out a particle counting of the oil.

2.2.7.1. ISO Cleanliness Code

The information in this section can be found in “How Important is the ISO Cleanliness code in Oil analysis”:

The ISO Cleanliness Code is the unit to report the fluid cleanliness covered under the ISO standard 4406:99. This standard determines the amount of particles in one millilitre of sample in three different size categories. These being $>4\mu\text{m}$, $>6\mu\text{m}$ and $>14\mu\text{m}$. ISO 4406:99 says that the amount of particles in each of these categories must be converted to an ISO code.

Table 2 shows the ISO codes and the amount of particles it can contain. [27]

MORE THAN (p/ml)	UP TO AND INCLUDING (p/ml)	ISO CODE
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8

Table 2| ISO cleanliness code [27]

Figure 21 shows an example of the results of an imaginary particle counting that is then related to the ISO Cleanliness code.

As you can see, the >4µm has a result of 9.721 particles/ml. If we look at the table, this is between 5.000 and 10.000. This means that the ISO code for >4µm is 20. For >6µm and >14µm this gives us an ISO code of 17 and 13 respectively.

The ISO cleanliness Code for this sample would then be 20/17/13. [27]

Table 1			ISO Cleanliness Class		
	PARTICLES/ML	ISO CODE	MORE THAN (µ/ml)	UP TO AND INCLUDING (µ/ml)	ISO CODE
> 4 microns	9,721	20	5,000	10,000	20
> 6 microns	1,254	17	2,500	5,000	19
> 10 microns	326		1,300	2,500	18
> 14 microns	73	13	640	1,300	17
> 21 microns	12		320	640	16
> 38 microns	5		160	320	15
> 70 microns	0		80	160	14
> 100 microns	0		40	80	13
			20	40	12
			10	20	11
			5	10	10
			2.5	5	9
			1.3	2.5	8

Figure 21| Example ISO cleanliness class [27]

2.2.7.2. Optical Microscopy Particle Counting ISO 4407

The information in this section can be found in “Particle counting-Oil Analysis 101”:

This type of particle counting is the original method used since the 1970s. It is done by putting a portion of the oil sample under a microscope and counting the particles manually. Even though this method may seem outdated and very time consuming (up to 3 hours for each sample), it is still considered the most reliable method to do a particle counting, due to it not having the limitations of some modern methods. Optical Microscopy Particle Counting is usually avoided because of its cost and time consumption. Nonetheless it is used when the customer requires a very clean oil and cannot afford to have any contamination because of highly sensitive and expensive systems.

Figure 22 shows a sample that is being examined under a microscope. [28]

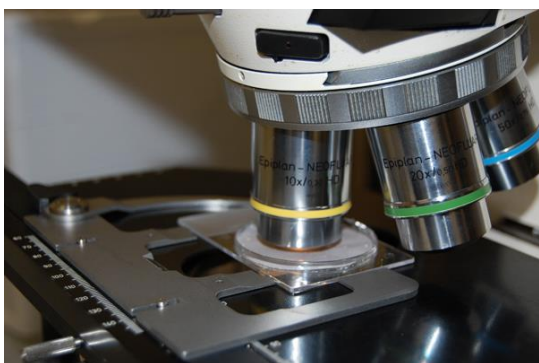


Figure 22| Microscope and sample [29]

2.2.7.3. Automatic Optical Particle Counting ISO 11500

The information found in this section can be found in “Particle counting-Oil Analysis 101”:

Automatic Optical Particle Counting is the most widely used particle counting method available. This particle counter is available in two versions, either a white light source or with a laser source.

Figure 23 shows a white light or light blockage particle counter using a light and a sensor. As the particles pass the detection zone, they block light and cast a shadow upon the sensor. This shadow causes the voltage produced by the sensor to drop proportionate with the size of the shadow and hence the size of the particle. [28]

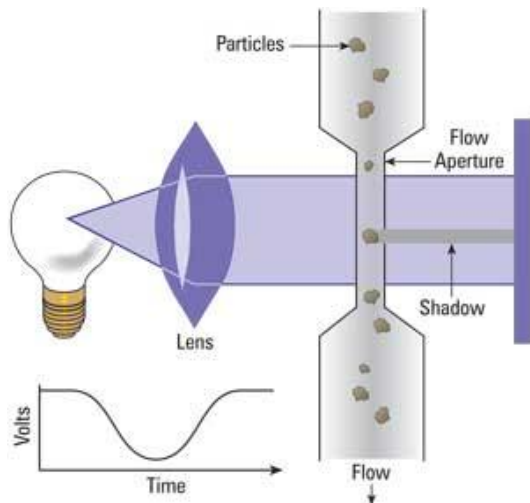


Figure 23| Light blockage particle counter [30]

Figure 24 shows a more modern version of the automatic particle counter that uses a laser instead of a normal light. This is called a light scattering particle counter. Because the laser is focussed into a tight beam, the light on the particles is scattered onto to sensor instead of casting a shadow. The voltage the sensor produces now increases and can be related directly to the size of the particle. Overall, a light scattering particle counter is more accurate and sensitive than its counterpart. [28]

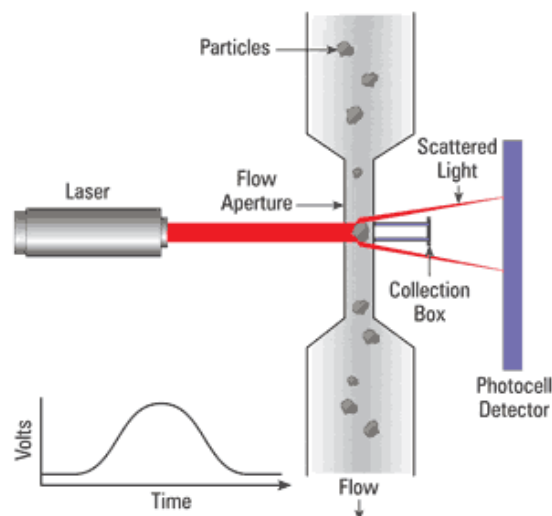


Figure 24| Light scattering particle counter [30]

There are certain problems that have to be considered with automatic particle counters.

The first one is that the particles are not perfectly spherical. This becomes an issue when you want to relate an irregular particle to a certain size.

For example, if you have a particle that is 40 μm on one side and only 5 μm on the other, as can be seen in Figure 25. Do we count it as a >14 μm or a >4 μm particle?

This is solved by developers of automatic particle counters, who have developed a compromise known as the equivalent spherical diameter. This says that the particle is counted in the size-range as if the particle, or rather its shadow or scattering effect, had a perfectly round shape. [28]

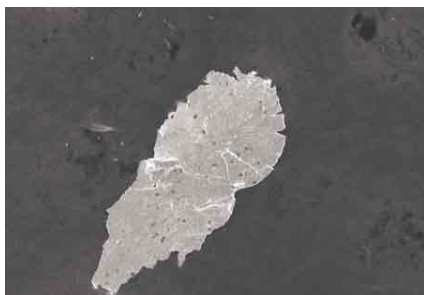


Figure 25| Irregular particle

Another problem is that a number of causes can give false positives.

For example, air bubbles and water can be detected as a particle by the machine. They solve this by diluting the oil sample with tuolene and propanol before inserting it into the machine. It is then homogenised and degassed to get rid of air bubbles in the oil which would otherwise get counted by the machine. The propanol does the same for the water in the sample by making it invisible. This makes sure that only the particles that are actually in the oil are counted. [28]

2.2.7.4. Pore Blockage Particle Counting BS3406

This information can be found in “Particle counting-Oil Analysis 101”:

The pore blockage method is another way to do an automatic particle counting. It uses a mesh screen with a defined pore size through which the sample is passed. Two instrument-types use this method. [28]

“One instrument measures the flow decay across the membrane as it becomes plugged while pressure is held constant, first with particles greater than 10 microns, and later by smaller particles as the larger particles plug the screen. The second measures the rise in differential pressure across the screen while the flow rate is held constant as it becomes plugged with particles. Both

instruments are tied to a software algorithm, which turns the time-dependent flow decay or pressure rise into an ISO cleanliness rating according to ISO 4406:99.” [28]

The advantage of this kind of particle counter is that it is not affected by air bubbles or water in the sample. [28] Though they do not have the same range, an optical particle counter does. [28] Pore blockage particle counters are mostly used for dark, heavily contaminated oils. [28]

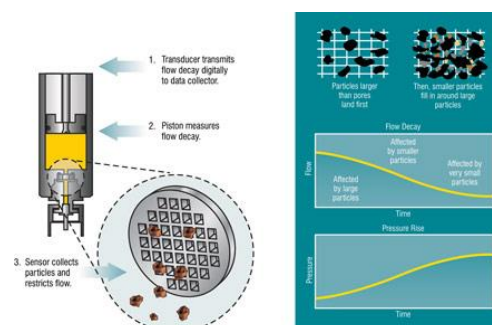


Figure 26| Pore blockage particle counter

2.2.8. Analytical Ferrography

Analytical ferrography is a Microscopic Examination and analysis of debris particles found in lubricants. [31] These particles could both be metallic or non-metallic debris. [31] Through this technique it is possible to trace metallic debris to their source (if it is in contact with oil) like bearings, gears, etc. [31]

Analytical ferrography is one of the most powerful tools to diagnose problems with the system, but is often overlooked or deemed unnecessary due to the high price and overall misunderstanding of its value. [31]

“The test procedure is lengthy and requires the skill of a trained analyst. As such, there are significant costs in performing analytical ferrography not present in other oil analysis tests. But, if the time is taken to fully understand what analytical ferrography uncovers, most agree that the benefits significantly outweigh the costs and elect to automatically incorporate it when abnormal wear is encountered.” [32]

2.2.8.1. Working principle of Analytical Ferrography

To perform an analytical ferrography the sample is diluted with solvent to make sure the wear debris can precipitate to the bottom of the lubricant. [31] The wear debris is then separated from the lubricant using a ferrogram slide maker. [31]

The diluted sample flows down a glass slide called a ferrogram which is specially designed to catch the debris. [32] This ferrogram rests on a magnetic cylinder which attracts the particles to the glass slide. [32] Due to the magnetic field, the particles align themselves in lines along the length of the ferrogram with the largest particles at the entry point and the smallest ones at the outlet. [32] The nonferrous particles and contaminants, who are not affected by the magnetic field, travel downstream while some are caught by the ferrous debris along the length of the ferrogram. The other nonferrous particles are removed with the flow of the lubricant. [32]

After the oil has been run through the ferrogram maker, the ferrogram is washed to remove any remaining lubricant. [32] This permanently attaches the particles to the slide. [32] Now the slide is examined using a bichromatic microscope. [32] This type of microscope uses both reflected (top) and transmitted (bottom) light to distinguish size, shape, composition and surface condition of the particles. [32] The particles are then classified to determine the type of wear and its source. [32]

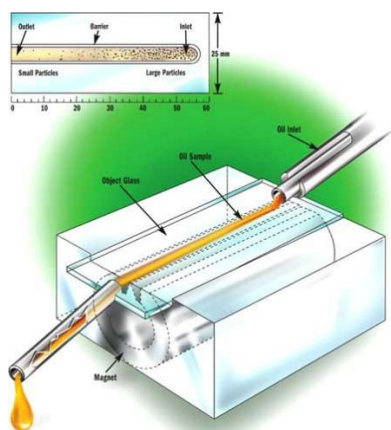


Figure 27 | Ferrogram slide maker [33]

2.2.8.2. Particle composition

To determine the type of wear and its source, the particles are classified into six categories.

“**White nonferrous particles**, often aluminium or chromium, appear as bright white particles both before and after heat treatment of the slide. They are deposited randomly across the slide surface with larger particles getting collected against the chains of ferrous particles. The chains of ferrous particles typically act as a filter, collecting contaminants, copper particles and Babbitt.” [32]

A picture of an aluminium particle can be seen in Figure 28



Figure 28| Aluminium particle on ferrogram [34]

“**Copper particles** usually appear as bright yellow particles both before and after heat treatment but the surface may change to verdigris after heat treatment. These also will be randomly deposited across the slide surface with larger particles resting at the entry point of the slide and gradually getting smaller towards the exit point of the slide.” [32]

A picture of a copper particle on a ferrogram can be seen in Figure 29



Figure 29| Copper particle on ferrogram [35]

“**Babbitt particles** consisting of tin and lead, Babbitt particles appear grey, sometimes with speckling before the heat treatment. After heat treatment of the slide, these particles still appear mostly grey, but with spots of blue and red on the mottled surface of the object. Also, after heat treatment these particles tend to decrease in size. Again, these nonferrous particles appear randomly on the slide, not in chains with ferrous particles.” [32]

A picture of a babbitt particle on a ferrogram can be seen in Figure 30

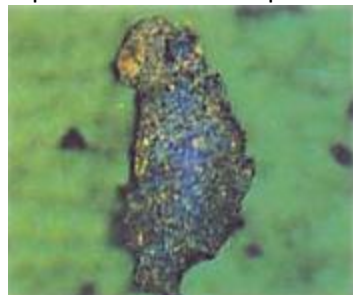


Figure 30| Babbitt particle on ferrogram [36]

“**Contaminants** are usually dirt (silica), and other particulates which do not change in appearance after heat treatment. They can appear as white crystals and are easily identified by the transmitted light source, that is, they are somewhat transparent. Contaminants appear randomly on the slide and are commonly dyked by the chains of ferrous particles.” [32]

A microscopic view of some silicon particles can be seen in Figure 31.



Figure 31| Silicon on ferrogram [37]

“**Fibres**, typically from filters or outside contamination, are long strings that allow the transmitted light to shine through. They can appear in a variety of colours and usually do not change in appearance after heat treatment. Sometimes these particles can act as a filter, collecting other particles. They can appear anywhere on the ferrogram, however they tend to be washed towards the exit end.” [32]

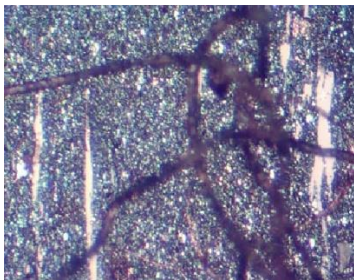


Figure 32| Cotton fibre under microscope

Ferrous particles are divided into five different categories. [32] They are identified using the reflected light source on the bichromatic microscope. [32] The transmitted light get blocked completely by the particle. [32]

- “**High Alloy Steel** - particles are found in chains on the slide and appear gray-white before and after heat treatment. The distinguishing factor in the identification between high alloy and white nonferrous is position on the slide. If it is white and appears in a chain, it’s deemed to be high alloy. Otherwise, it’s considered white nonferrous The frequency of high alloy on ferrograms is rare.” [32]
- “**Low Alloy Steel** - particles are also found in chains and appear gray-white before heat treatment but then change color after heat treatment. After heat treatment they usually appear as blue particles but can also be pink or red.” [32]

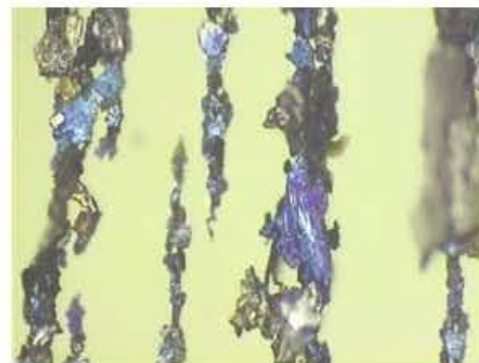


Figure 33| High alloy (grey) and low alloy (blue/purple) steel on ferrogram [38]

- **“Dark Metallic Oxides** - deposit in chains and appear dark gray to black both before and after heat treatment. The degree of darkness is indicative of the amount of oxidation.” [32]
Figure 34 shows dark metallic oxides on a ferrogram.

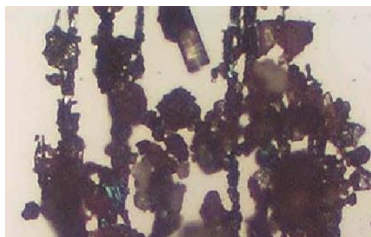


Figure 34| Dark Metallic oxides on ferrogram [38]

- **“Cast Iron** - particles appear gray before heat treatment and a straw yellow after the heat treatment. They are incorporated in chains amongst the other ferrous particles.” [32]

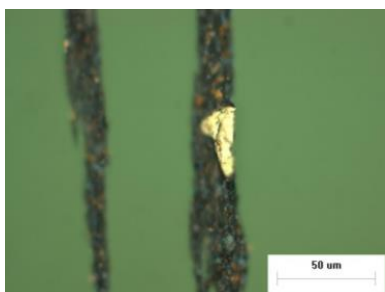


Figure 35| Cast iron particle (yellow) on ferrogram [39]

- **“Red Oxides (Rust)** - polarized light readily identifies red oxides. Sometimes they can be found in chains with the other ferrous particles and sometimes they are randomly deposited on the slide surface. A large amount of small red oxides on the exit end of the slide is generally considered to be a sign of corrosive wear. It usually appears to the analyst as a “beach” of red sand.” [32]

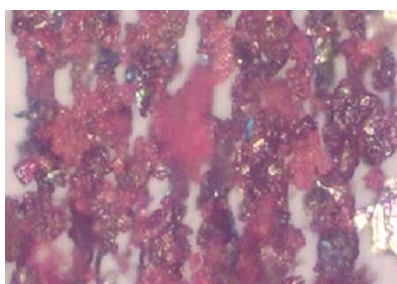


Figure 36| Red oxides on ferrogram [38]

After classifying the composition of the particles the analyst rates their size using a micrometer scale on the bichromatic microscope. [32] Particles with a size of at least 30µm are given a rating of “severe” or “abnormal”. [32] This rating means that something is wrong with the running conditions of the system and action, albeit corrective or preventive, must be taken. [32]

2.2.8.3. Shape of particles

The shape of the particles also gives a lot of information about the origin of the wear. The ones below are some of the most common ones.

- **Normal Rubbing Wear**

“**Description:** Ferrous particles, less than 30 microns in size. Some Sources: Rubbing wear is typically found in both reciprocating and non-reciprocating units.” [38]

“**Comments:** On a ferrogram the particles tend to align in chains. Normal ferrous wear can be categorized as low alloy, cast iron and high alloy steel.” [38]

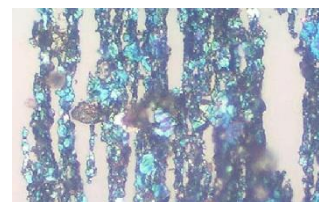


Figure 37| Rubbing wear [38]

- **Spherical particles**

“**Description:** A relatively smooth spherical particle. Spheres are created in bearing fatigue cracks, typically roller bearings.” [38]

“**Comments:** . Spheres are often precursors of bearing spalls. A large increase in quantity is indicative of imminent spalling.” [38]



Figure 38| Spherical particles [38]

- **Cutting wear Particles**

“**Description:** Shaved metal particles that look like wood shavings from a lathe. Seen in sleeve bearings and shaft couples. Abrasives embedded in soft bearing or burrs on hardened metals create these wear particles.” [38]

“**Comments:** Worm drives have a tendency to create this type of particle. When seen it indicates abnormal wear.” [38]



Figure 39| Cutting wear particles [38]

- **Sliding particles**

“**Description:** Metallic particles, both normal and severe, with sliding striations along one or more surfaces. Sliding wear can be created when two parts of a machine scrape together.” [38]

“**Comments:** Sliding striations are often a good clue as to what part of a machine is causing wear.” [38]

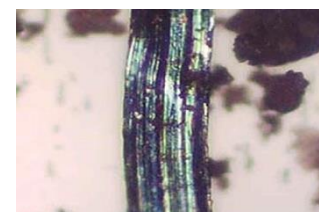


Figure 40| Sliding particle [38]

- **Laminar Particles (Bearing wear particles)**

“**Description:** Thin, smooth particles which appear to have been rolled flat. Roller bearings, areas where high-pressure angled or lateral contact occurs.” [38]

“**Comments:** Wear created by extraneous particle if the laminar has small holes or indents.” [38]



Figure 41| Laminar particle [38]

- **Scuffing or Scoring Particles (Gear Wear).**

“**Description:** Metallic particles, both normal and severe, with sliding striations along one or more surfaces.” [38]

Comments: Looks like sliding wear



Figure 42| Scuffing particle [49]

2.3. Periodicity and position

As previously mentioned the periodicity and position of all the samples must be reviewed and adjusted.

2.2.9. Periodicity

The absolute minimum periodicity for oil samples is one year, no matter what kind of system it is. With this periodicity a decent tracking of the oil condition cannot be done and even less so for the machine condition. A more frequent sampling gives a better view on the critical condition of the oil and machine.

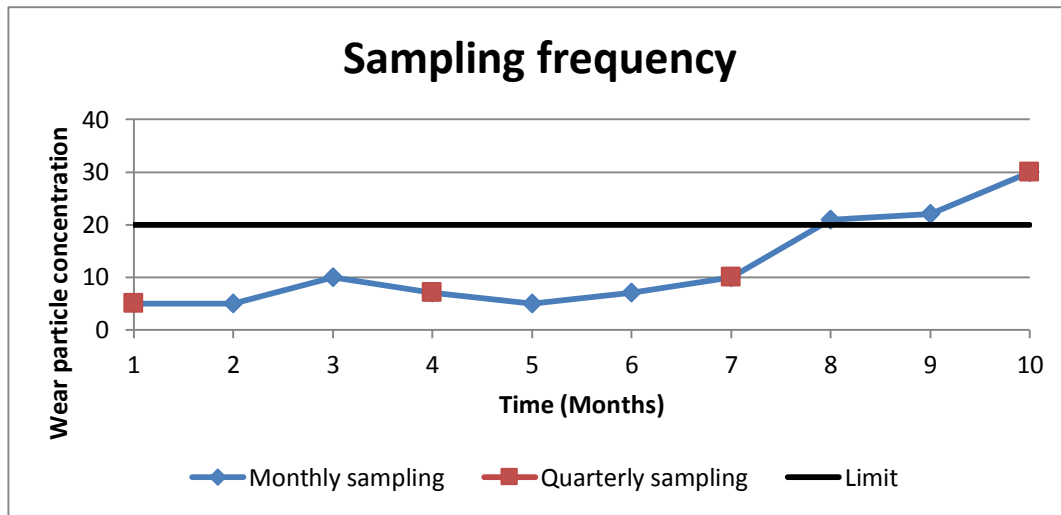


Figure 43 | Monthly vs quarterly sampling

As you can see in the chart, a monthly sampling will indicate a breach of the limits quicker than a quarterly sampling. If a problem occurs, for example the amount of iron in the oil is so high the system will break down with a long unscheduled downtime as consequence. A quarterly sampling will only notice the problem after 3 months. By then it could be too late and the system might be damaged with an unscheduled downtime of the system as a consequence. A more frequent sampling makes a quicker response to the problem possible.

Documentation states a periodicity of 500 hours is recommended for oil analysis on refrigerating compressors, if the system is in continuous use. That translates to an oil sample every 3 weeks – 1 month.

Equipment Type	Normal Use Sampling Frequency (Hours)	Normal Use Sampling Frequency (Calendar)	Occasional Use Sampling Frequency (Calendar)
Industrial and Marine			
Steam Turbines	500	Monthly	Quarterly
Hydro Turbines	500	Monthly	Quarterly
Gas Turbines	500	Monthly	Quarterly
Diesel Engines-Stationary	500	Monthly	Quarterly
Natural Gas Engines	500	Monthly	Quarterly
Air/Gas Compressors	500	Monthly	Quarterly
Refrigeration Compressors	500	Monthly	Quarterly
Gearboxes-Heavy Duty	500	Monthly	Quarterly
Gearboxes-Medium Duty		Quarterly	Semi-Annually
Gearboxes-Low Duty		Semi-Annually Annually	Annually
Motors-2500 hp and higher	500	Monthly	Quarterly
Motors-200 to 2500 hp		Quarterly	Semi-Annually
Hydraulics		Quarterly	Semi-Annually
Diesel Engines-On and Off Highway	150 hours/10,000 miles	Monthly	Quarterly

Table 3 | Recommended sampling frequency [40]

2.2.10. Position

The position where the sample is taken is important to give a good representation of the oil quality. For instance, when you take a sample at the bottom of the sump, a higher amount of contaminants can be found. The reasoning behind this is that the contaminants get time to sink to the bottom of the sump. A recommended position to take the oil samples is in the return-line after the compressor.

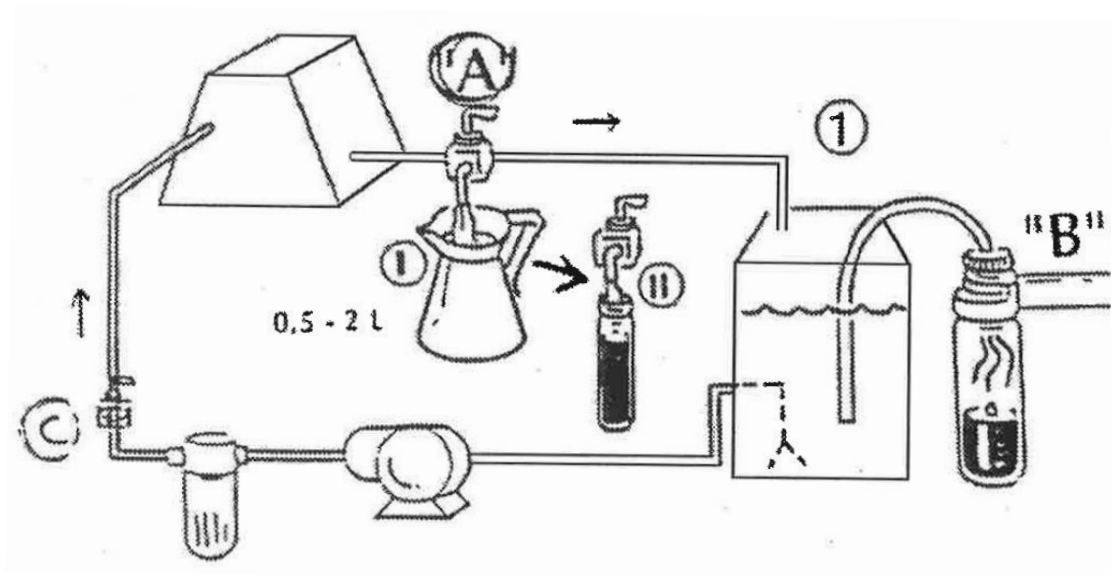


Figure 44 | Example sampling spots [41]

The best position in the example above would be point "A". This is the return-line, right behind the system. If this is not possible, the sample can be taken from point "B". This is in the oil sump, but as long as it is done in a turbulent flow and slightly below the surface this is a solid option. Point "C" would be the worst placement. Since it is behind the filter, a lot of the wear particles will be removed and it will give a bad representation of the oil leaving the machine. However, if you would like to check the quality of the filter, this is an appropriate spot.

As mentioned, the best position to take a sample is in a bend. In a bend the flow is turbulent, which will stir and mix the oil and result in the most homogenous and representative sample.

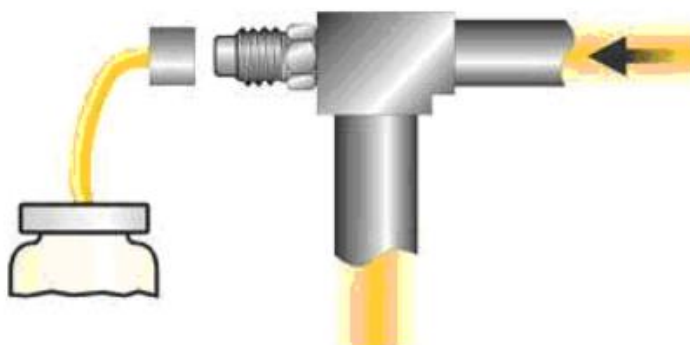


Figure 45 | Oil sample taken in a bend [42]

3. CERN cryogenic installations and oil analysis

3.1. Introduction to a cryogenic installation

“Cryogenics is the branch of physics that deals with the production and effects of very low temperatures.” [43]

Cryogenics permit us to use one of the characteristics of materials at very low temperatures called superconductivity.

Superconductivity is a phenomena that occurs with several metals and ceramic materials. [44] When these materials are cooled to very low temperatures, ranging from near 0 K to the temperature of liquid nitrogen (77 K), their electrical resistance drops to (almost) zero. [44]

The temperature at which a material becomes superconductive is called its critical temperature (T_c). [44] Superconductive Niobium-titanium (NbTi) conductors are used in the accelerators of the LHC, which has a T_c of 10 K. [44]

These very low temperatures, ranging from 77 Kelvin (K) to 1.8 K (-196.15 °C to -271.35 °C), are achieved using cryogenics installations. There are 31 cryogenics installations (Figure 46) spread over the CERN facilities, used for:

- LHC accelerators;
- LHC detectors;
- Other detectors (Such as CAST);
- Test areas and services (Such as SM18). [45]

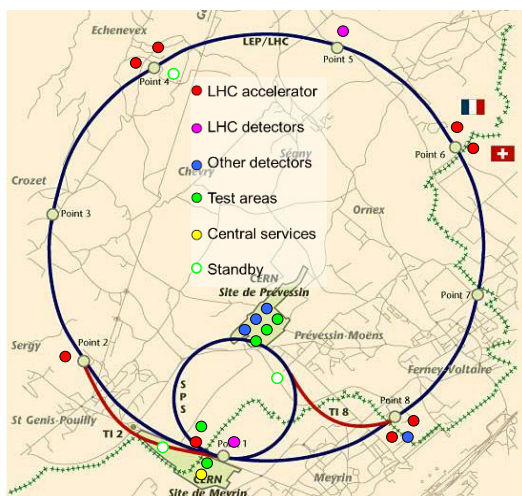


Figure 46| CERN cryogenic systems [45]

The LHC, as was previously mentioned, has a circumference of 27 km. These 27 kilometres are split into 8 sections, called points (where point 1 and 1.8 can be seen as the same point). The cryogenic systems are spread around the even points 2, 4, 6 and 8 as well as an additional system in point 1.8. Each of these cryogenic installations cover a part of the LHC of around 3.3 km. Each side at each point also has a side A and B. This makes it simpler to name the different systems. Figure 47 shows the different cryogenic installations spread around the 8 points.

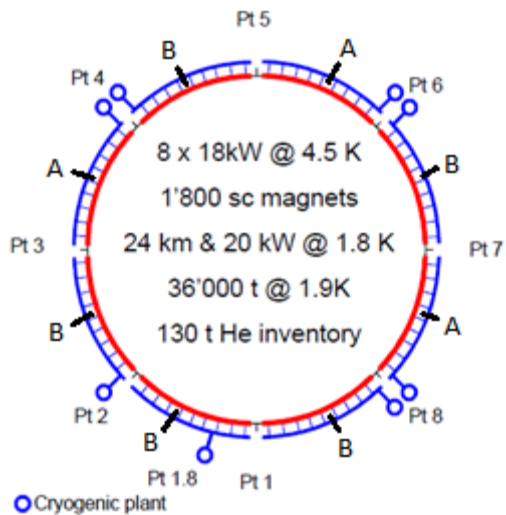


Figure 47| Cryogenic plants and points

Figure 48 shows the typical operation of a LHC even point and its cryogenic installations. Liquefied helium at 80K is supplied to a cold box by a compressor station above ground. In the cold boxes, that are both above- and underground depending on the type of system, the helium fluid is cooled and purified. The cold box contains heat exchangers and turbo-expanders that provide the cooling needed to cool the helium down to 4.5K or 1.8K if necessary. The cooled down helium is then pumped through a sector of 3.3 km to the different superconductive magnets and experiments. The remaining helium is pumped back to the storage.

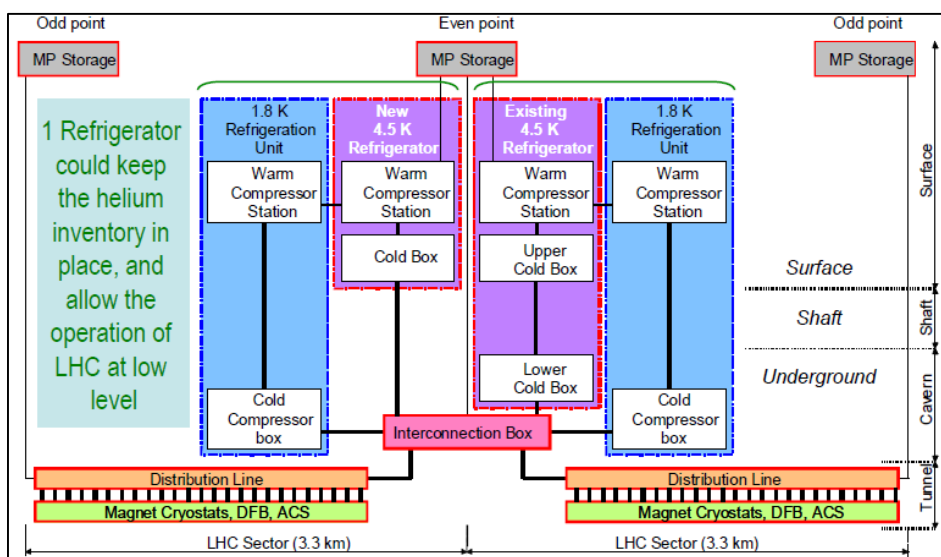


Figure 48| Typical LHC even point [46]

3.1.1. Terminology of the compressor stations

To name the different compressor stations at CERN a code is used for each separate system. For example, QSCCB-18-CO1.

- Q = Cryogenic
- S = Surface (Can be above or underground)
- C = Cold (Can be a cold or warm compressor)
- C = Compressor
- B = Side B (There can be a side A and a side B at each point.)
- 18 = Point 1.8 (The placement around the LHC)
- CO1 = Compressor 1 (There can be multiple compressors)

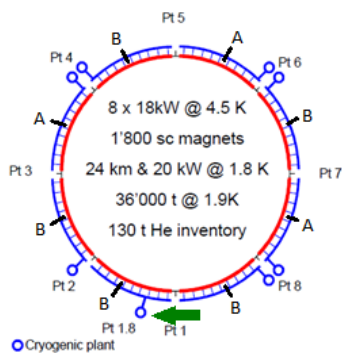


Figure 49| Position of QSCCB-18-CO1

Figure 49 shows the position of this compressor.

As a second example, QSCA-6-CP6.

- Q = Cryogenic
- S = Surface
- C = Compressor (Lack of 2nd C means it is a warm compressor)
- B = Side A
- 2 = Point 6
- CO6 = Compressor 6

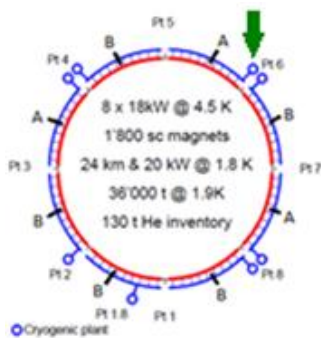


Figure 50| Position of QSCA-6-CP6

Figure 50 shows the position of this compressor.

3.2. General inventory of compressor stations at CERN

The compressor stations at CERN can be classified into 2 main categories:

- System 1
- System 2

These categories have been made to make a quick separation between the huge amounts of compressor systems in use at CERN.

3.2.1. System 1A

System 1A consists of 1 compressor with one phase separator. The oil sample is taken at the bottom of the phase separator. The basic principle of system 1A is shown on Figure 51.

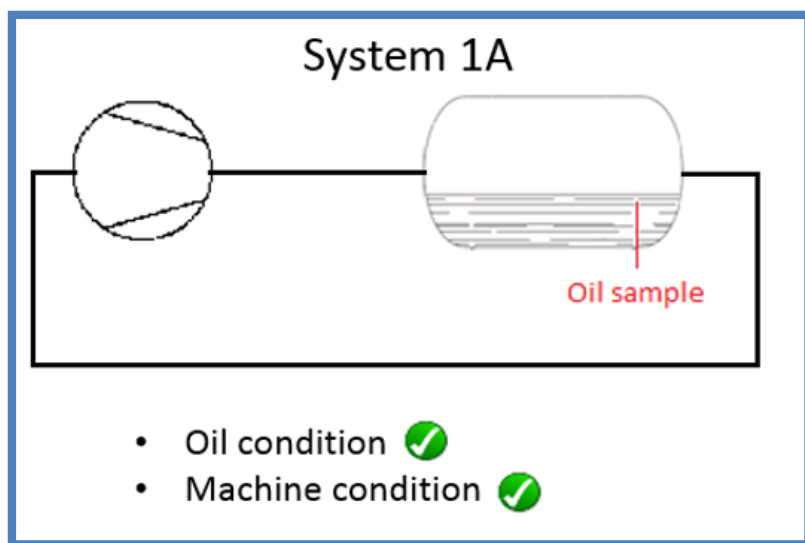


Figure 51 | Principle of System 1A

In theory, oil analysis could be applied to this system with the current procedures since the oil sample, taken in the phase separator, can be directly related to the compressor.

However, the sampling location has to be reviewed since modern oil sampling procedures recommend the sample to be taken in the return line and preferably in a bend, where turbulent flow is created. Also the periodicity has to be redefined, since one sample every year is not sufficient.

3.2.2. System 2

System 2 consists of two stages. The first stage (low pressure → medium pressure) is composed of one or several compressors (called boosters) and one phase separator. The same for the second (high) stage. At CERN, some installations can have up to 6 compressors in each stage. The oil samples are all taken in the second phase separator.

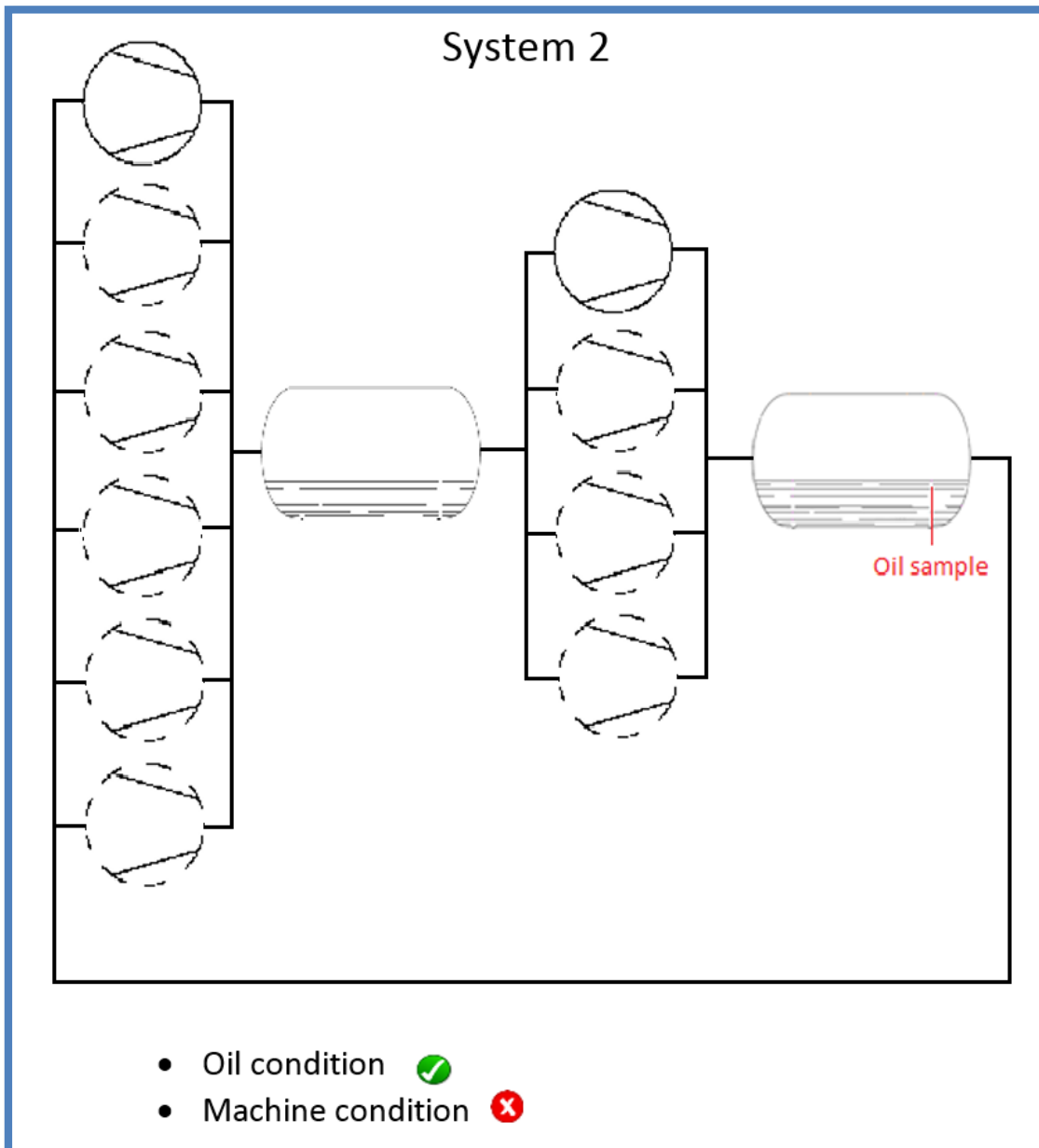


Figure 52 | Principle of system 2

Due to the sample being taken in the second phase separator, the results cannot be related to a single compressor unit which is necessary to determine the machine condition. The sampling spot and periodicity will have to be changed and customised for the separate compressor units.

3.3. Screw- vs Piston compressor

The information in this section can be found in “Piston vs Rotary Screw Compressors: A Short Comparison for the Collision Market”:

The majority of the compressors in use at CERN are oil injected screw compressors (Figure 53). These compressors use 2 screws that rotate at high speeds to displace air and produce pressure.



Figure 53| Screw compressor [47]

Screw compressors have several big advantages over piston compressors. The main ones being:

Operating temperature and moisture: A piston compressor typically works at an operating temperature of around 150 – 200 °C, while a screw compressor operates around temperatures of 75 -100°C. The advantage here is that because the piston compressor runs warmer, the air or gas it compresses can contain more moisture. This means that an extra component to dry the air is needed. [47]

Constant flow: Because of the constant rotating speed of the screw compressor, the air flow it delivers is more continuous. They also have an unlimited operating cycle because they cannot overheat. Piston compressors on the other hand cannot run constantly. Therefore they are often oversized and a tank is almost always used to make up for this flaw. **Error! Reference source not found.** shows a comparison of the duty cycles of a rotary compressor and a piston compressor. [47]

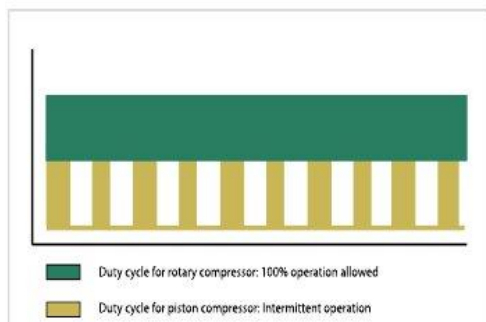


Figure 54| Comparison of duty cycles [47]

Maintenance: Normal maintenance for piston compressors is easier than for its rotary counterpart and cheaper on top of that. Routine maintenance for screw compressors on the other hand is a lot more points to check. They will however not wear as quickly as piston compressors, which prevents them from breaking down and having to be revised. [47]

Vibration and sound: A screw compressor produces less sound and vibration by far and therefore does not need to be put in a separate room. [47]

3.4. Current oil analysis practices at CERN

In the year 2000, CERN started working with the Oelcheck Laboratory to do oil analysis on the cryogenics compressors. This was a very basic sampling to check the oil condition and for contamination. The tests performed included:

- ICP spectroscopy to check the chemical elements,
- Viscosity and viscosity index test,
- Karl Fischer titration to check the water content,
- Particle counting to check the cleanliness class.

There then was a large break in the oil analysis practices, until 2008, when CERN started doing oil analysis on all the cryogenics compressors. This was done with a periodicity of once per year. The tests performed were the same as in 2000, except that an IR spectroscopy was performed and the particle counting wasn't done.

In 2011 oil samples were taken from some of the plain bearings to check their oil condition and for signs of wear.

In 2012 CERN started doing particle counting again on top of the previously performed tests to check the cleanliness class of the oil.

Up until this point, an oil sample is taken once per year from the cryogenic compressors. The goal for these samples is to check the oil condition and contamination.

A timeline for the oil analysis practices at CERN can be found in Figure 55.

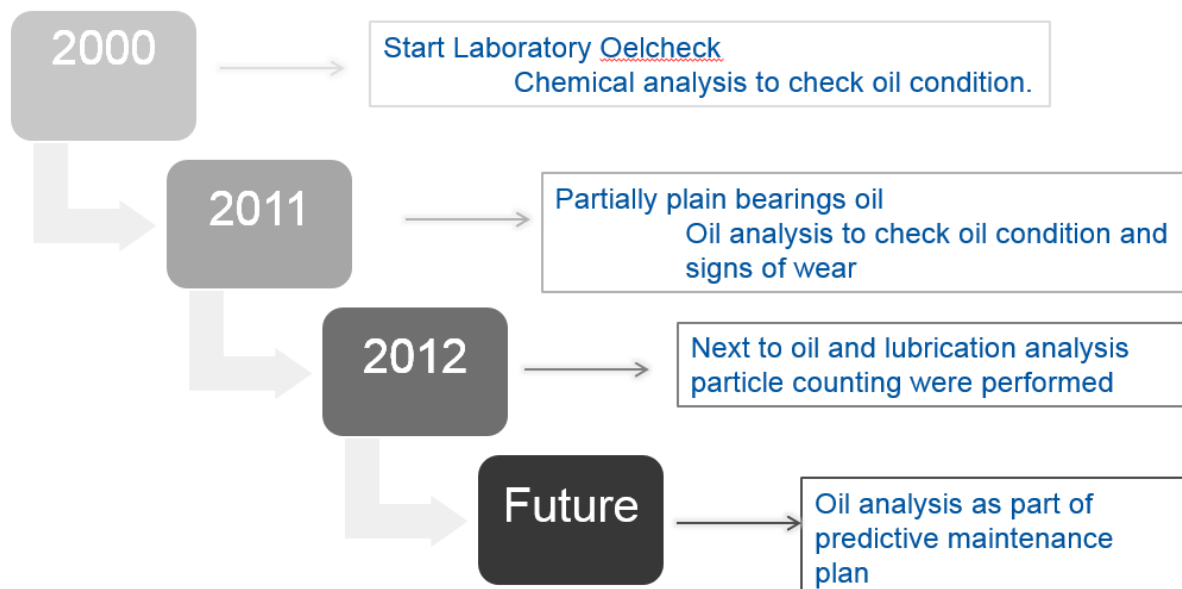


Figure 55| History oil analysis at CERN

4. Applying oil analysis to Kaeser HSDV760 compressor

To improve the oil analysis plan for the compressor systems at CERN, there was decided to put focus on a single system, one that was simpler. It gives a broader oil analysis plan that is more straightforward to adapt to the more complicated compressor systems, which can often be very different from each other. The Kaeser HSDV760 is the ideal compressor system because of its simplicity.

4.1. Kaeser HSDV760 compressor

The HSDV760 compressor system was developed by a German company called Kaeser Kompressoren and placed in CERN by Air Liquide in 2006. There are eight of these systems in use at CERN. Two in point 1.8, two in point 2 and four in point 6. Their task is to propel the helium gas from its tank to the cold boxes.

The specific system the oil analysis plan was developed for is QSCCB-18-CO1, but it should be applicable without modification to other compressor stations of the same type.

The Kaeser HSDV760 is a complete air package, which means it contains an oil injected screw compressor system, an oil separator, filters, coolers, etc. It has a closed oil circuit, which makes it easier to make the oil analysis plan, since only one compressor will have to be considered.

Figure 56 | PID of Kaeser HSDV760 on page 35 shows the Piping and Instrumentation Diagram (P&ID) of the system. The green arrows represent the oil and the red arrows signify the helium gas.

It works as follows:

The helium gas enters the system through the gas inlet (K1) and at the same time the compressor sucks oil into it. The mixture of gas and oil is now compressed and exits the compressor under high pressure. The mixture then goes through the outlet pipe until it enters the phase (oil) separator. The oil drops down into the oil separator tank, while the helium gas goes up into the separator cartridge where the remaining oil is removed.

The helium gas now continues to go through to the watercooler where it is cooled down before going to the gas outlet (K2). It then flows to the next stage (which is no longer part of this system), the cold box, where it will be cooled down and liquefied again before entering the cooling circuit of the LHC.

The oil gets filtered before it is cooled down by the watercooler. It then is filtered again by nine filters that are parallel with each other in sets of three. It then gets sucked back into the compressor for another cycle.

More information and technical drawings of the system can be found in the Appendix A on page 50.

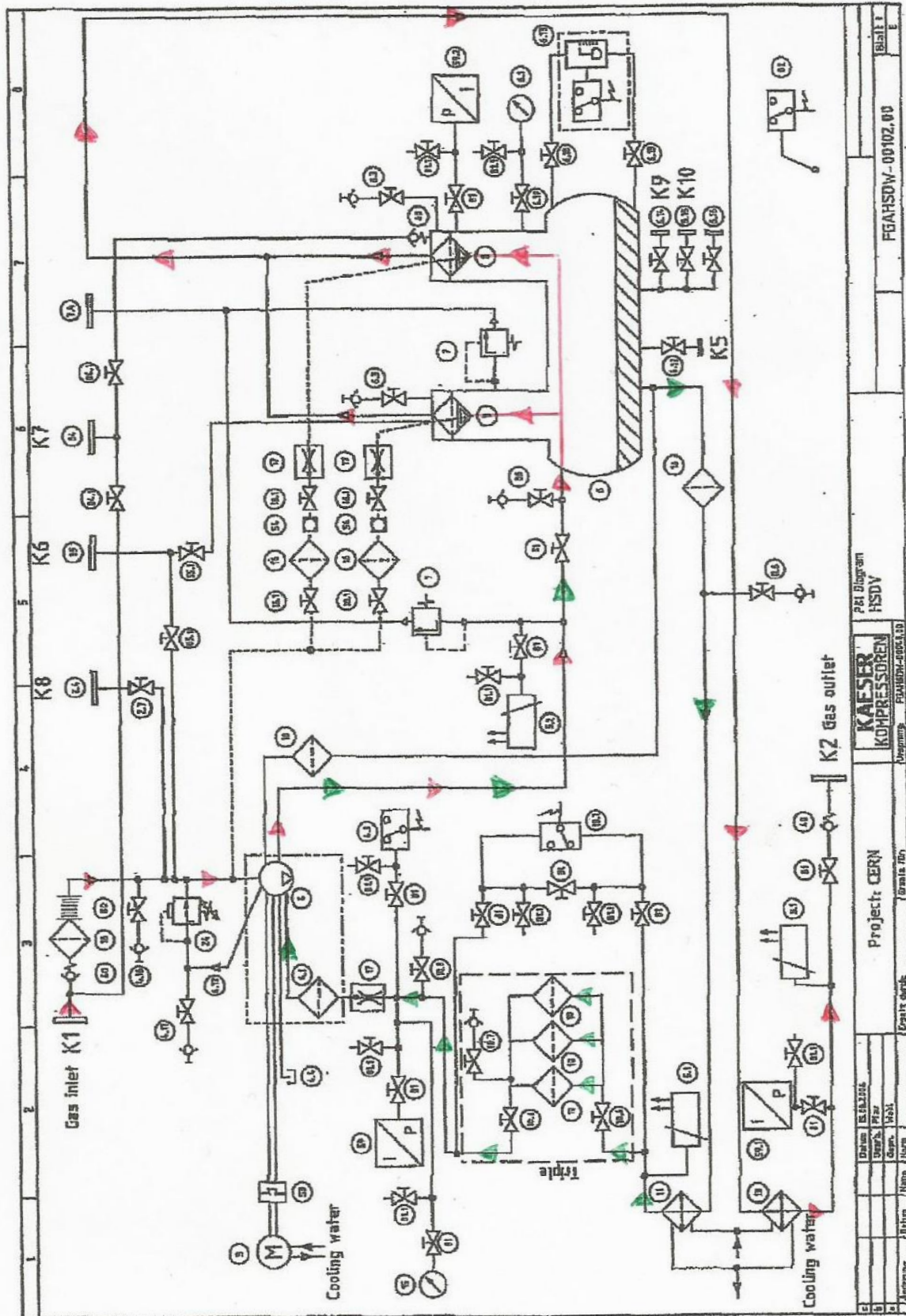


Figure 56| PID of Kaeser HSDV760 [48]



Figure 57| Complete system HSDV 760 Point 1.8

Figure 57 shows the complete system QSCCB-18-CO1 in Point 1.8. As you can see there is an identical system behind it, which is QSCCB-18-CO2.

Indicated by the numbers are some important parts of the system:

- ①: Compressor unit
- ②: Phase separator
- ③: Gas inlet
- ④: Oil inlet
- ⑤: Oil-Gas mixture outlet
- ⑥: Gas outlet
- ⑦: Oil filters 3x3

4.2. Cognis Breox B35 Oil

The oil used in most of the compressor systems at CERN is Cognis Breox B35.

It is a synthetic lubricant with water insoluble characteristics with a viscosity of 33 cSt at 40 °C.

“The **BREOX** B-Series are a range of mono initiated propylene oxide homo-polymers manufactured to provide a viscosity range from 15 to 335 cSt @ 40°C” [49]

The Datasheet for this product can be found in the Appendix B on page 52.

4.3. Review of sampling spot

The first thing that needed doing was reviewing the sampling spot. This was originally done at the bottom of the phase separator of the system. This however, is not what the documentation states is the best spot to take the sample because debris can collect at the bottom of the tank. Therefore there was opted to take the sample in the return line of the system, right after the compressor outlet in a ninety degree bend as can be seen in Figure 58. This spot already had a valve and had the ideal location because it would give a representative sample and was easily accessible to take the samples.

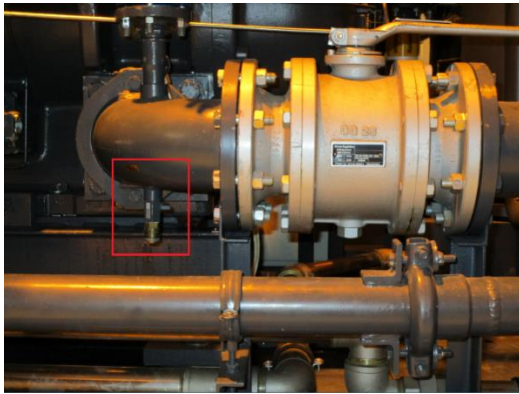


Figure 58 | Valve at compressor outlet

To test if the spot was indeed better, a sample was taken from both the old sampling spot in the phase separator and this new spot. The samples were taken by Serco, the maintenance company at CERN, at the same conditions. The only difference was that the new sampling spot needed a new tubing and connection for a hose. The sample was then sent to the Oelcheck laboratory to be tested.

Measurement results		
Cleanliness class	ISO 4406 (1999)	--/18/15
> 2 µm	Particles/100ml	247994
> 5 µm	Particles/100ml	151802
> 10 µm	Particles/100ml	60919
> 15 µm	Particles/100ml	30540
> 25 µm	Particles/100ml	11864
> 50 µm	Particles/100ml	2782
> 100 µm	Particles/100ml	512
> 150 µm	Particles/100ml	160
> 250 µm	Particles/100ml	64
> 500 µm	Particles/100ml	0
Weight increase filter	mg/kg	16,5

Figure 59 | Particle counting old spot

Measurement results		
Cleanliness class	ISO 4406 (1999)	--/16/14
> 2 µm	Particles/100ml	96240
> 5 µm	Particles/100ml	58475
> 10 µm	Particles/100ml	24136
> 15 µm	Particles/100ml	14467
> 25 µm	Particles/100ml	6320
> 50 µm	Particles/100ml	1523
> 100 µm	Particles/100ml	152
> 150 µm	Particles/100ml	0
> 250 µm	Particles/100ml	0
> 500 µm	Particles/100ml	0
Weight increase filter	mg/kg	53,8

Figure 60 | Particle counting new spot

At first, everything seemed normal and values were very close to each other, because the oil was very clean. But when the results of the particle counting were compared, we saw that the values for the old spot (Figure 59) were a lot higher than those of the new spot (Figure 60).

This was enough proof that the new sampling spot was actually better than the old one and should from then on be used to take the oil samples.

The complete oil analysis reports can be found in the Appendix C starting on page 54.

4.4. Setting the test slate

The test slate of an oil analysis program is the collection of tests that will be conducted on the samples. The tests carried out are very specific for the type of machine (compressor, motor, etc.) and the goal of the oil analysis. If the company only wants to check the condition of the oil, some tests are redundant.

Choosing a well-rounded and customised test slate is one of the most important steps in setting up an oil analysis program. This makes sure the information gained is maximised from a relatively narrow and cost-effective set of tests. [25]

To set the test slate, a difference must be made between primary and secondary tests. A primary test provides broad but relatively shallow details and will be conducted on every sample taken from the machine. A secondary test provides a very specific type of information that very precisely relates to the system. These tests are mostly carried out when some specific conditions are met with the outcome of an oil analysis report.

Table 4 shows some commonly used tests and their relevance for certain conditions of the machine.

What is analyzed	1. Fluid Properties Physical and chemical properties of used oil (aging process)	2. Contamination Fluid and machine destructive contaminants	3. Wear Debris Presence and identification of wear particles
Possible Tests:			
Particle counting	○	●	◐
Moisture analysis	○	●	○
Viscosity analysis	●	◐	○
Ferrous density	○	○	●
Analytical ferrography	○	◐	●
AN/BN	●	◐	◐
FTIR	●	◐	○
Patch test	○	●	◐
Flash point	◐	●	○
Elemental analysis	●	◐	●
	Proactive	Proactive	Predictive

● Primary benefit
◐ Minor benefit
○ No benefit

Table 4 | Commonly used tests and their utility [50]

The test slate used at CERN for all the compressors is a kit developed by the Oelcheck laboratory called the “Set 3 Yellow”. It consists of a basic test slate with primary tests including:

- **ICP spectroscopy** to check the wear metals, additives and contamination
- **PQ-index** to check the amount of ferromagnetic debris in the sample
- **FT-IR spectroscopy** to check multiple parameters including water, fuel, soot and certain additives.
- **Viscosity (40°C/100°C) and viscosity index**
- **Karl Fischer water content**
- **Acid Number** to check the additive depletion, acidic contamination and oxidation.
- **Particle Counting** to check the ISO cleanliness code and the amount of particles in the oil.

This test slate is very well balanced and should give a very extensive look at the overall health of the compressor systems at CERN. It provides information about the oil condition, contamination and machine condition.

It could however be improved with a secondary test to give an even clearer look at the machine condition.

This is why it is recommended to include an **Analytical Ferrography** in the test slate to carry out in some cases. This can be very useful when an increase of the wear metals or PQ-Index is noticed. In that case this test can give you the precise location of the cause.

A more comprehensive explanation about the tests in this subsection can be found in subsection “2.2. Oil analysis methods” starting on page 7.

4.5. External or internal oil analysis

An important question to think off when implementing an oil analysis program is if the analysis will be done by an external lab or internal, on an in-house laboratory. This is hard to answer and depends on the amount of samples that have to be taken and the tests that will have to be carried out.

If the cost of an internal laboratory outweighs the cost of sending the samples and having them analysed by an external laboratory, it is better to invest in an in-house lab. The cost of buying an in-house laboratory and educating/hiring personnel has to be considered in this calculation though.

Another option is to invest in a basic in-house laboratory on which the standard test (ICP spectroscopy, PQ-index, FT-IR spectroscopy, etc.) can be carried out and sending samples to an external lab for more extensive tests like analytical ferrography. This makes it possible to carry out quick testing with results within the hour and to send a sample to the external for more extensive inspection.

Figure 61 shows the OSA4 Microlab[®] from Spectro Scientific. This is an all-in-one lab that carries out basic tests like elemental analysis, particle counting, viscosity and oil chemistry.



Figure 61 | OSA4 Microlab[®] from Spectro Scientific

The amount of samples sent from CERN to the Oelcheck laboratory is not high at this point, because samples of the oil in the compressor systems are only taken about once per year. Right now, it would not be worth investing in an internal lab and to keep using the Oelcheck laboratory. However, as a fully operation oil analysis program will gradually be put into operation, this number will increase one sample every month at the least. At that point it may be interesting to consider an internal lab, but only if the costs are cheaper than the external solution.

4.6. Writing new sampling procedure

The problem with the past procedures for oil analysis at CERN is that they are very general. There is only one procedure that covers all the compressor systems. It gives information about the safety and how to take the sample, but contains no visualising pictures or any other information that could help avoiding errors in the sampling. Like drawing from the wrong port or forgetting to drain a small amount before sampling. This problem made the procedure also very hard to read.

Documentation states that a good sampling procedure must contain the following elements:

- Sampling goal
- Sampling location
- Sampling frequency
- Material requirements
- Sampling method
- Potential sources of interference
- Safety considerations

To solve this a new procedure has been written for the Kaeser HSDV 760 compressor system. The following changes have been applied to improve the old one:

- The procedure has been adapted to the specific system (Kaeser HSDV 760)
- Images have been added to some of the information to make it easier to understand
- Information about the new sampling spot and periodicity has been added
- Special precautions that have to be paid attention to have been written down

The old procedure and the newly written one can be found in the Appendix D starting on page 60.

4.7. Setting thresholds and classes for key parameters

When an oil analysis report is received, there is a lot of information to go through. It can be hard to find a way of processing all that material and arrange it according to importance.

Choosing key parameters and giving them a class of importance can help in this process. A key parameter is a factor that has to be checked in the oil analysis report because it is an indicator of the machine and oil health.

Choosing thresholds sets boundaries which indicate the gravity of the value a key parameter on the oil analysis report has. It determines the category of the issue together with the trending.

4.7.1. Thresholds

The thresholds of the key parameters give an indication of the severity a value on the oil analysis report has. It then gets placed into one of three categories.

- Nominal
- Issue
- Major Issue

The Thresholds of the Key parameters for CERN can be found in the appendix E on page 66.

It shows the value for each of the categories. If, for example, the oil analysis report says the iron has a value of 12 ppm it would mean the iron is in the category “Issue”.

Once the issue category for a certain parameter is determined, the class of impact is defined as well.

4.7.2. Class of impact

For the compressor systems at CERN the key parameters are split into three classes of impact. The parameters are classified by the impact it could cause to the systems.

- High/Critical impact
- Medium/Limited impact
- Low/Limited impact or Not present

For the Kaeser HSDV 760 and all the other compressor systems, the most likely problems that can happen are bearing failures, changes in viscosity and contamination of particles (both ferrous and non-ferrous).

This however does not mean the other parameters aren't important. They just have less chance to cause any serious impact to the machines.

It is also useful to define which goal of oil analysis each parameter belongs to. For example by ordering into machine condition, oil condition and contamination and on top of that mentioning their possible origin.

In the Appendix F on page 67 the classes of the key parameters can be found with the possible origin of the anomaly in the oil analysis report.

It shows the three classes of impact, the main goal of oil analysis they indicate, the key parameters and their possible origin.

4.8. Trending of results

Next to setting thresholds it is also important to make a trending of the oil analysis results.

A trend is: “A pattern of gradual change in a condition, output, or process, or an average or general tendency of a series of data points to move in a certain direction over time, represented by a line or curve on a graph.” [51]

Or simply put: The gradual change of the value a certain parameter has over time.

Trending is hard to do if oil analysis just started on a system (or on a new sampling spot) because there are not enough past data to compare. In this stage the thresholds that have been set must be relied on. To have a representative trend, at least four results must be available.

Simply relying on thresholds to make decisions is not enough to use oil analysis as a tool for predictive maintenance. A trending tells the oil analysis expert if the value of a certain parameter is increasing. This can be an important indicator something is wrong in the system that has to be monitored.

For CERN a trending of the analysis results is fairly easy since the Oelcheck laboratory includes a tool in the oil analysis database to make a trending. The oil analysis reports also list the values of the past three reports so an on the fly comparison of the values can be made.

Figure 62 shows the trending of iron on the QSCB-18 system on the Oelcheck database. In the last sample (14/10/2014) the iron is elevated in the trending. This is a clear indication that the iron will have to be monitored. The last sample was critical due to elevated water values.

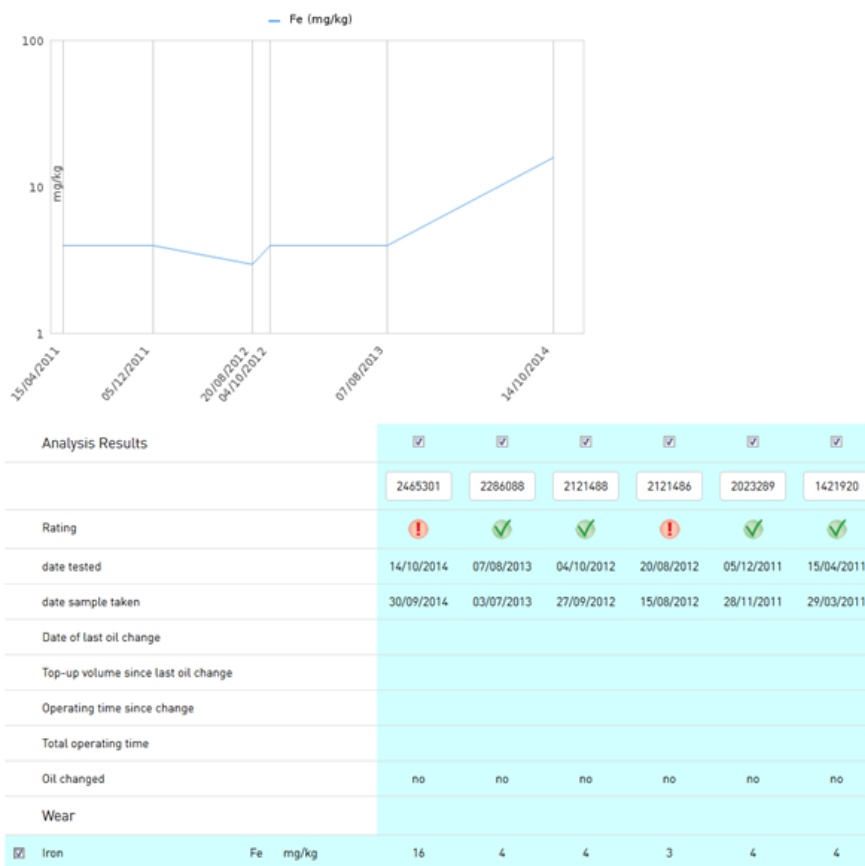


Figure 62 | Trending Iron QSCB-18 Oelcheck laboratory

4.9. Decision tree

To combine all of the previous information a procedure must be made to decide if measures or more samples must be taken, if monitoring must be done, etc.

This is done using a decision tree because it gives a graphical and structured way of action starting from the oil analysis report, all the way until the problem is solved.

To start off the decision tree is divided into the three categories:

- Nominal
- Issue
- Major Issue

The category that is chosen depends on the value of the parameter with regards to the thresholds. More information about the Thresholds can be found in Subsubsection 4.7.1 on page 41.

The complete decision tree can be found in Appendix G on page 68. This is an overall view that will make it quick and easy to make decisions with the results of the analysis.

To make things more clearly visible it is split up into the three main categories on the next pages.

4.9.1. Category “Nominal”

The tree structure for Category “Nominal” can be found in Appendix G page 69.

When a certain parameter on an oil analysis report is put in the category “Nominal” the next step is to look at the classes of impact (Appendix F).

If the class is “**Low Impact**” or “**Medium Impact**” like Tungsten or Silicon respectively, the normal *sampling period* continues and no further action is taken.

If the class is “**High Impact**”, there is a possibility to make a *Work Order (WO)* of the type *Observation (OB)* is made to put the parameter under observation. The reason can for example be that the trend says it has been increasing gradually.

Afterwards the normal sampling period continues and no further action is taken.

4.9.2. Category “Issue”

The tree structure for Category “Issue” can be found in Appendix G on page 70.

When a parameter is put into the category “Issue” next step is to look at the classes of impact (Appendix F).

If the class is “**Low Impact**” first a *Parent WO* of the type *OB* is made with a *Low priority*, this means other more urgent matters get priority.

Then there has to be decided if one or multiple *Child WOs* have to be made for a *Preventive action (PC or Preventif conditionnel in French)* or *Corrective Action (CA or Correctif Amelioration in French)* with *Low Priority* during a *Long Shut Down*.

Afterwards the next sample will be taken on the regular interval.

If the class is “**Medium Impact**” a *Parent WO* for *OB* will be written with a *Medium priority*.

Then the decision has to be made if one or more *Child WOs* have to be made for *PC* or *CA* with *Medium priority* during a *Long Shut Down* period.

The last step is to decide if the *sampling period* has to be reduced.

If the class is **“High Impact”** a *Parent WO* for *OB* with a *high priority* has to be made. At the same time the decision has to be taken if an *Analytical Ferrography* has to be carried out. If the parameter is a wear metal or PQ-index, a *Child WO* for another sampling and *analytical ferrography* has to be made. Once the *analysis report* arrives, the cause for the anomaly should be known and a *Child WO* can be made for *PC* or *CA* with *High Priority* during a *Long Shut Down*. The last decision is if the *Sampling period* has to be reduced.

4.9.3. Category “Major Issue”

The tree structure for category “Major Issue” can be found in Appendix G on page 71.

When a parameter is put into the category “Major Issue” the next step is to look at the classes of impact again (Appendix F).

If the class is **“Low Impact”** a *Parent WO* of the type *OB* with *Low Priority* must be made.

The next step is to decide if one or multiple *Child WO* of type *PC* or *CA* with *Low priority* for intervention during a *Long Shut Down* must be made.

The last step is the decision if the next *sampling* must be on a shorter period.

If the class is **“Medium Impact”** a *Parent WO* of type *OB* must be made with a *Medium Priority*.

At the same time is the parameter was *Water*, a *Child WO* must be made to do *another sampling* to check if the previous one was taken under the *right conditions*.

Then a *Child WO* can be made for *Type PC* or *CA* with *Medium Priority* during *Medium Shut Down*.

Afterwards a sampling must be done right after the *PC* or *CA* has been completed.

If the class is **“High Impact”** a *Parent WO* of type *OB* must be made with a *High Priority*.

At the same time, if the parameter is a *wear metal* or *the PQ-index*, a *Child WO* for *Sampling and Analytical Ferrography* must be done.

When the *analysis report* is received, the cause of the problem should be known and a *Child WO* of type *PC* or *CA* with *High Priority* for *Short Shut Down* must be made.

The next question is if the equipment must be *stopped* immediately to prevent further damage. If so, the machine will be stopped. Otherwise a *sample* will be taken *immediately after the PC* or *CA* has been carried out.

5. Conclusion

The subject of this thesis was developing an oil analysis plan to use as a tool for predictive maintenance for the cryogenic compressor systems at CERN. An oil analysis plan was already implemented for these systems but was only used to check the condition of the oil.

This brought us to my research question: “How can the oil analysis plan of the cryogenics plants at CERN be improved?”.

To find an answer I started by researching everything I could about oil analysis. From Best Practices for taking oil samples and sampling spots, to learning everything about an Analytical Ferrography. I also learned a lot about the compressor systems and their value at CERN.

This all contributed to an oil analysis plan that was developed for one of the Kaeser HSDV 760 compressors. This project took all of the knowledge I gathered over my six months at CERN.

The oil analysis plan for the Kaeser HSDV 760 compressor system is a great foundation to build onto and modify to the needs of the other, more complex compressor systems at CERN. Also the question whether or not it is worth implementing an internal oil analysis site is something left to do.

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viii. Appendix

A. Additional information Kaeser HSDV760 Compressor



Technical Specification

1 Technical Specification

1.1 Vacuum Low Pressure Package

Model	HSDV 760
Maximum vacuum	100 mbar
Maximum back pressure	5 bar (a)
Effective helium inlet flow at	
– 335 mbar / 4,395 bar (a)	70 g/s
– 231 mbar / 2,648 bar (a)	44 g/s
– 181 mbar / 2,211 bar (a)	35 g/s
Operating temperature approx.	75 – 100 °C (depending on inlet conditions and ambient temperature)
Weight	14000 kg
Diagrams:	
Dimensional drawing	T 0062.01
Pipe and Instrument Flow Diagram (P & I Diagram)	
.....	FSOMEBANORD–00016.00
.....	FGAHSWDW–00102.00
Electrical diagram	
.....	SHSD760.WMH–01103.01
.....	SHSD760.WMH–01104.01

1.2 Sound Pressure Level

Operational status of the vacuum low pressure package	
Inlet operation, vacuum package runs under: nominal speed, approx. 200 mbar vacuum, nominal inlet displacement capacity	
Setting up conditions:	
Free field measurement	
Measurement to CAGI/PNEUROP PN8 NTC 2.3:	
Sound pressure level	105 dB (A)

1.3 Motor

Drive motor:	
Rated power	300 kW
Rated speed	1500 min ⁻¹
Specification class	IP 55

1.9 Recommended Oils

Lubricant / cooling oil of type Breox B 35 is specified for KAESER vacuum packages.

Attention! Always use the same type and brand of oil when topping up. Never mix different types of oil.

Use only the oil specified!

During an oil change, drain all the oil from the oil separator tank, oil cooler and the oil pipes.

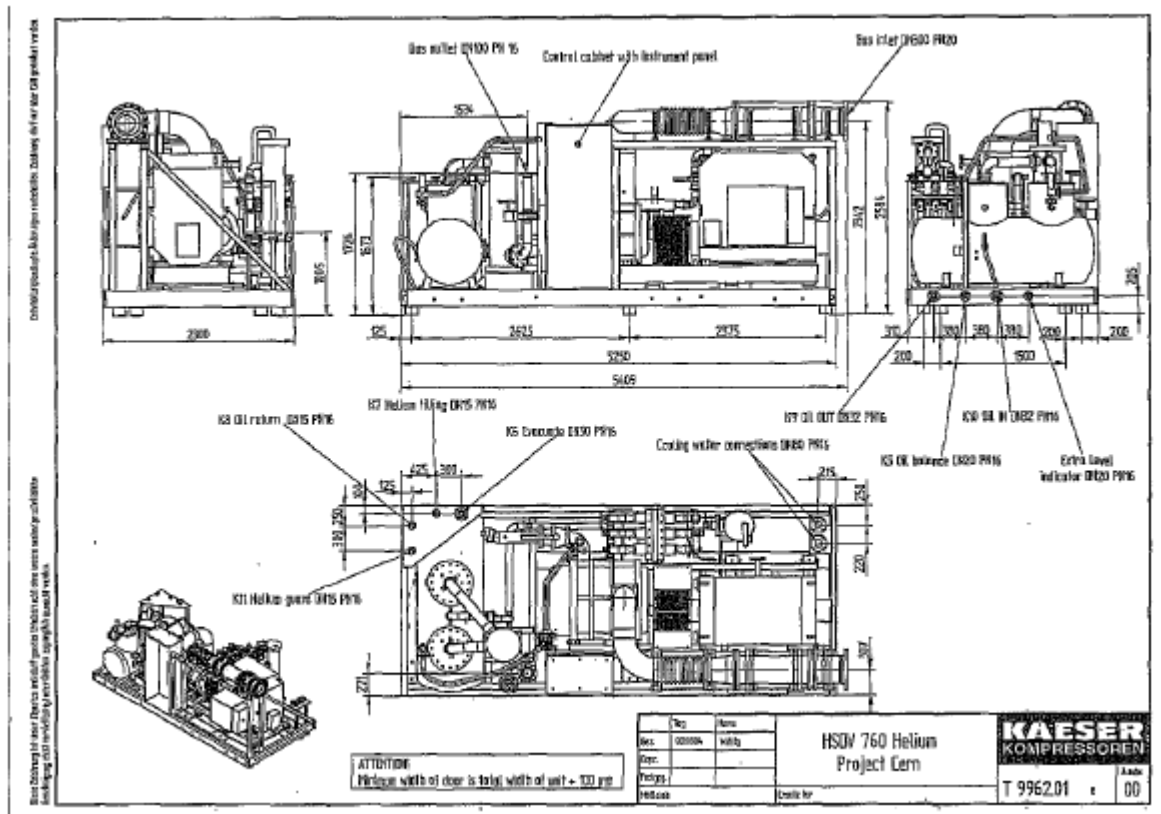
Always order this special oil through Air Liquide so as not to endanger the warranty.



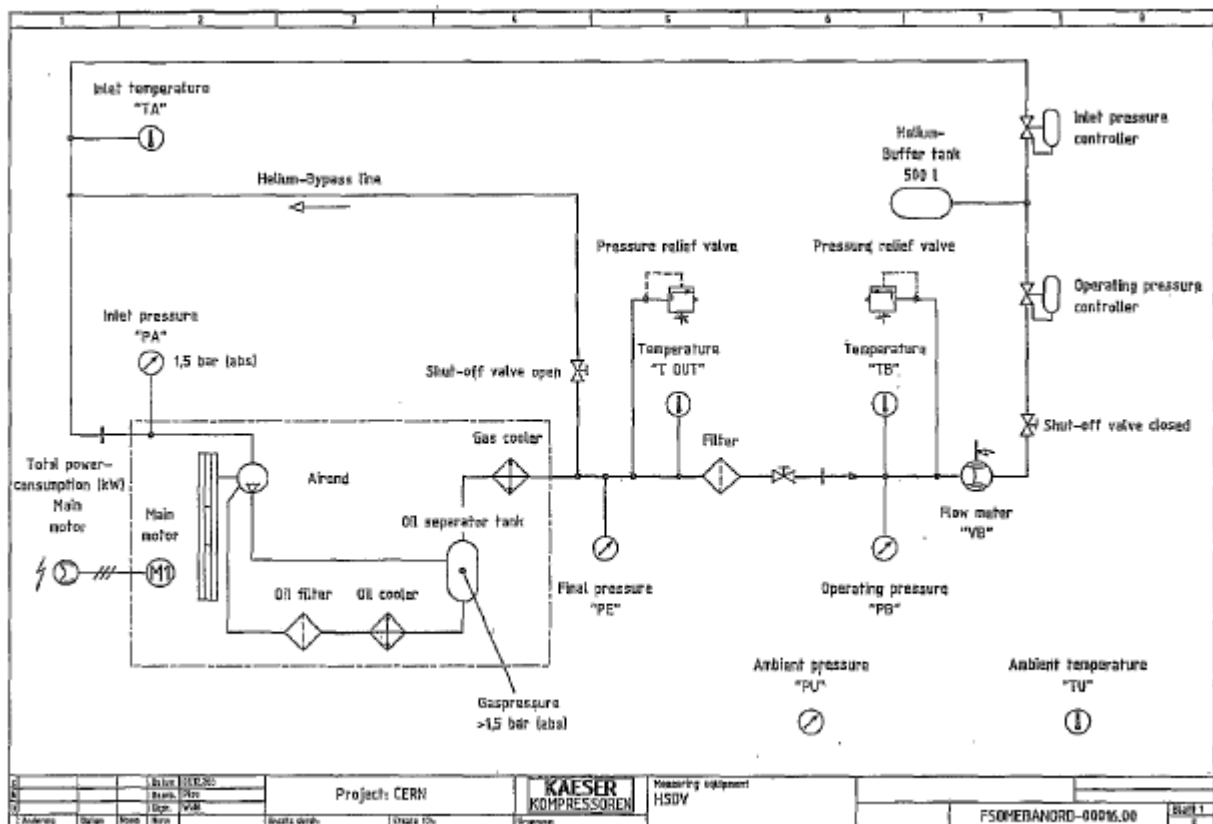
Cooling oil can get very hot. Allow the vacuum package to cool down before carrying out work on the oil separator system.

Attention! Proceed according to the enclosed oil technigram when handling cooling oil.

Technical documentation [48]



Dimensional drawing [48]



Construction and operation [48]

B. Cognis Breox B35 Oil Data Sheet [49]



synlubestechnology
BREOX B 35

INTRODUCTION

The BREOX B-Series are a range of monol initiated propylene oxide homo-polymers manufactured to provide a viscosity range from 15 to 335 cSt @ 40°C.

These products find extensive application when manufacturing and formulating various water insoluble lubricants for example:

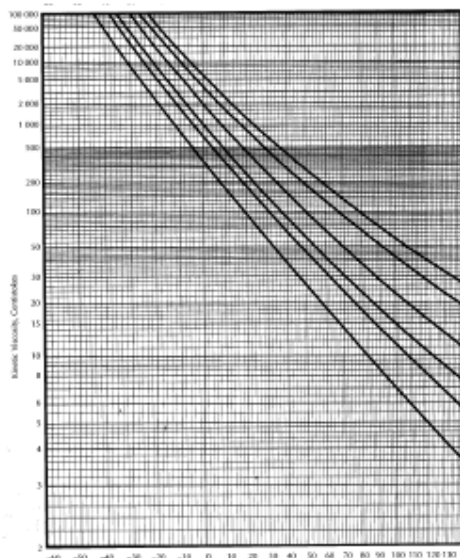
- Gear and Calender lubricants
- Compressor lubricants
- Metal working formulations
- Textile lubricants

In addition the BREOX B-Series from B75 upwards are FDA approved under 21 CFR 178.3570 (Incidental contact with food) and can therefore be used in instances where the potential for food contamination exists.

TYPICAL PHYSICAL PROPERTIES

		B 35
Viscosity	cSt @ 40°C	33
Viscosity	cSt @ 100°C	6.7
Viscosity Index	ASTM D 2270	189
Pour point, °C	ASTM D 97	-60
Refractive Index	N ^o D	1.45
Specific Gravity	20 / 20°C	0.98
Flash Point, °C	COC	208
Vapour Pressure	mm Hg 20°C	<0.001
Water Content	% by wt	<0.25
Specific Heat	kJ / kg K	1.95
Ash	ASTM D 482	<0.01
Surface Tension, 20°C	Dynes / cm	35 – 40

VISCOSITY vs. TEMPERATURE BEHAVIOUR



Remarks

Handling & Safety:
Storage:

Revision-No.

2.3-08.2004 Effective August 17, 2004

The product can be stored for at least 2 years at ambient storage conditions and temperature without any deterioration.

All products in the text marked with an @ are trademarks of the Cognis group.

The information on product specifications provided herein is only binding to the extent confirmed by Cognis in a written Sales Agreement. COGNIS EXPRESSLY DISCLAIMS ANY RESPONSIBILITY FOR THE SUITABILITY OF THE PRODUCTS FOR ANY SPECIFIC OR PARTICULAR PURPOSES INTENDED BY THE USER. Suggestions for the use and application of the products and guide formulations are given for information purposes only and without commitment. Such suggestions do not release Cognis' customers from testing the products as to their suitability for the customer's intended processes and purposes. Cognis does not assume any liability or risk involved in the use of its products as the conditions of use are beyond its control. The user of the products is solely responsible for compliance with all laws and regulations applying to the use of the products, including intellectual property rights of third parties.

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Hardley, Hythe, Southampton, SO45 3ZG, UK - Phone +44 (0) 2380 894666
- Fax +44 (0) 2380 234113


F_S



C. Complete oil analysis reports

Oil analysis report Old spot

LAB REPORT



Kerschelweg 28 · 83098 Brannenburg · Germany
Tel. +49 8034-9047-0 · info@oelcheck.de

+49 8034-9047-210

Unit ID **QSCCB18-CP1**

Component **Compresseur de gaz [Helium]**

Current sample number **2816162**

page 1 of 3

OELCHECK GmbH · Postfach 1116 · 83094 Brannenburg

CERN
Site de Meyrin
1211 GENÈVE 23
SCHWEIZ

Model: **1.6918.0 1001**

Manufacturer: **Kaeser**

Oil brand name: **Cognis Breox B 35**


Oil quantity in system: **400**

Diagnosis for the current laboratory values

Wear metals are only present in negligible concentrations. Hardly any abrasive or corrosive wear is therefore visible. The water content has slightly decreased. Please observe further changes with the next sample. I recommend that you send the next sample at the next service interval or at your regular inspection for trend analysis.

Dipl.-Wirtsch.-Ing. (FH) Rainer Schöpf

Sample Rating



normal

ANALYSIS RESULTS		Current sample	4 previous samples not shown		
LAB NUMBER		2816162	2465346	2286082	2121464
SAMPLE RATING		✔	✔	✔	✔
Date tested		25.06.2015	14.10.2014	02.07.2013	13.07.2012
Date of sample taken		22.06.2015	30.09.2014	10.06.2013	28.06.2012
Date of last oil change		-	-	-	-
Top-up since change		-	-	-	-
Operating time since change		-	-	-	-
Total operating time		-	-	-	-
Oil changed		-	-	-	-
WEAR					
Iron	Fe mg/kg	1	0	0	0
Chrome	Cr mg/kg	0	0	0	0
Tin	Sn mg/kg	0	1	2	1
Aluminum	Al mg/kg	0	0	0	0
Nickel	Ni mg/kg	0	0	0	0
Copper	Cu mg/kg	0	0	0	0
Lead	Pb mg/kg	0	0	0	0
Molybdenum	Mo mg/kg	0	0	0	0
Manganese	Mn mg/kg	0	-	-	-
PQ index	-	< 25	< 25	< 25	< 25
CONTAMINATION					
Silicon	Si mg/kg	1	2	1	1
Potassium	K mg/kg	1	0	0	1
Sodium	Na mg/kg	0	0	0	0
Tungsten	W mg/kg	-	3	-	-
Water K. F.	ppm	1011	3851	672	410
OIL CONDITION					
Viscosity at 40°C	mm ² /s	35.01	35.77	34.62	34.69
Viscosity at 100°C	mm ² /s	7.20	7.33	7.25	7.15
Viscosity index	-	176	176	181	175
Oxidation	A/cm	-	-	-	-
Color	Color index	0.5	0.5	1.0	0.5
ADDITIVES					
Calcium	Ca mg/kg	0	0	0	1
Magnesium	Mg mg/kg	0	0	0	0
Boron	B mg/kg	0	0	1	1
Zinc	Zn mg/kg	0	0	1	0
Phosphorus	P mg/kg	0	0	0	4
Barium	Ba mg/kg	0	0	0	0
Sulphur	S mg/kg	31	< 10	18	< 10
ADDITIONAL TESTS					
AN / NN	mgKOH/g	< 0.01	0.06	< 0.01	< 0.01

Additional sample details

Type of compressor construction:
Screw compressor

Bottle and Cap



Infrared Spectrum





Description of standards and test methods: www.oelcheck.com



LAB REPORT

Unit ID **QSCCB18-CP1**
 Component **Compresseur de gaz [Helium]**
 Current sample number **2816162**



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page 2 of 3

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 SCHWEIZ

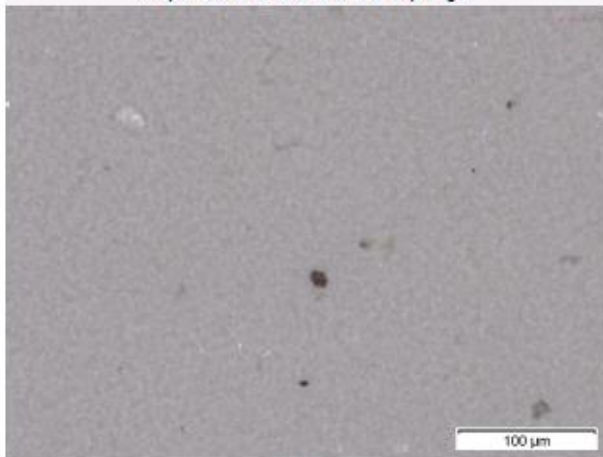
Model: **1.6318.0 1001**
 Manufacturer: **Kaeser**
 Oil brand name: **Cognis Breox B 35**
 Oil quantity in system: **400**

Diagnosis of microscopic particle analysis

The values for the nonmetallic contaminants and for wear particles are within the normal range.

Dipl.-Wirtsch.-Ing. (FH) Rainer Schöpf

Representative section of test diaphragm



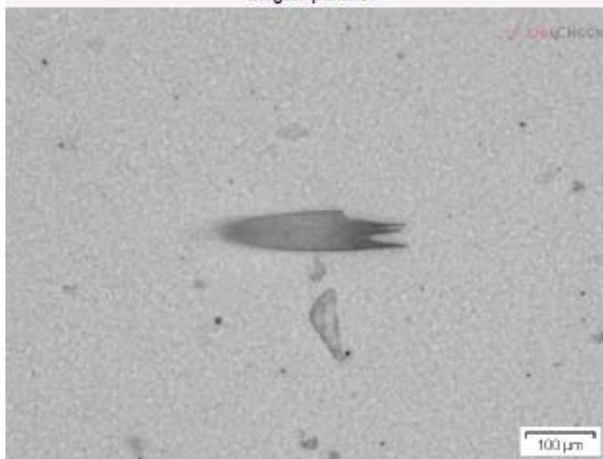
ANALYSIS RESULTS

LAB NUMBER	Current sample
Date tested	2816162
Date of sample taken	25.06.2015
Date of last oil change	22.06.2015
Top-up since change	-
Operating time since change	-
Total operating time	-
Oil changed	-

Olympus particle analysis

Cleanliness class	ISO 4406 (1999)	-/18/15
> 5 µm	Particles/100ml	151802
> 15 µm	Particles/100ml	30540

Largest particle



Testing membrane



Description of standards and test methods: www.oelcheck.com

Scan QR code
 Send new sample



LAB REPORT

Unit ID **QSCCB18-CP1**
 Component **Compresseur de gaz [Helium]**
 Current sample number **2816162**

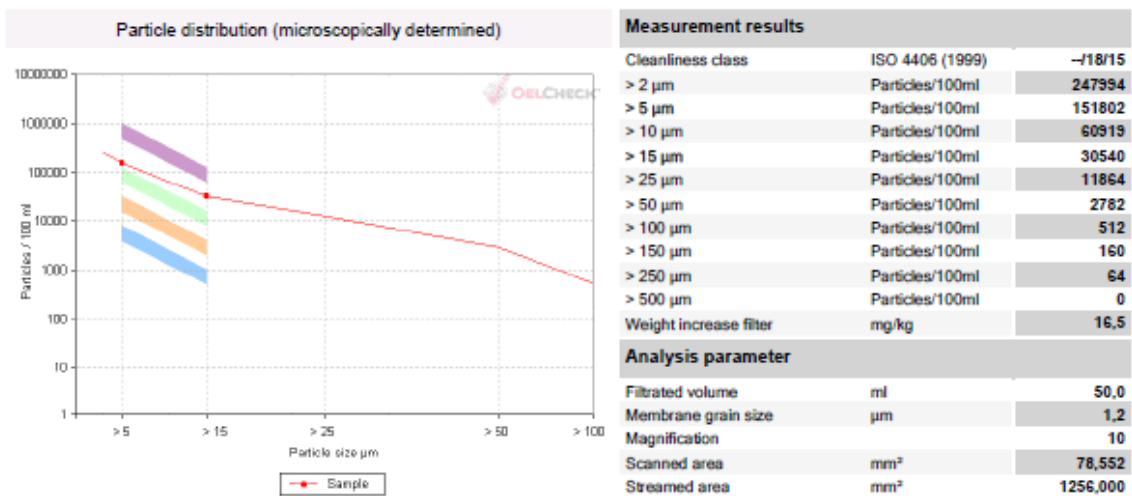


page 3 of 3

CERN
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 SCHWEIZ

Model: **1.6318.0 1001**
 Manufacturer: **Kaesser**
 Oil brand name: **Cognis Breox B 35**
 Oil quantity in system: **400**

Detailed information for microscopic particle analysis



Typical cleanliness classes

- Planetary-/ and spur gears
- Plain Bearings in turbine systems
- Prop valve hydraulic /Rolling bearing paper machines
- Servo valve hydraulic



Description of standards and test methods: www.oelcheck.com

Scan QR code
 Send new sample



Oil analysis report new spot

LAB REPORT

Unit ID **QSCCB-18-C01-TEST**
 Component **Compressor**
 Current sample number **2816163**



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page 1 of 3

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CERN
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 SCHWEIZ

Model: **Pas Indiqué**
 Manufacturer: **KAESER**
 Sample from: **Gas compressor**
 Oil brand name: **Breox B 35**
 Oil quantity in system: **400 l**

Sample related to: Test prelevement sortie HP compresseur

Diagnosis for the current laboratory values

Wear metals are only present in negligible concentrations. Hardly any abrasive or corrosive wear is therefore visible. Viscosity and additive levels are in the normal range. The cleanliness class of the oil complies with the requirements. Please observe further changes with the next sample. I recommend that you send the next sample at the next service interval or at your regular inspection for trend analysis.

Dipl.-Ing. (FH) Klaus Turnwald

Sample Rating



normal

ANALYSIS RESULTS		Current sample	Previous samples	Additional sample details	
LAB NUMBER		2816163		Gas type: HELIUM	
SAMPLE RATING		✓		Bottle and Cap	
Date tested		25.06.2015			
Date of sample taken		22.06.2015			
Date of last oil change		-			
Top-up since change		-			
Operating time since change		-			
Total operating time		-		Infrared Spectrum	
Oil changed		-			
WEAR					
Iron	Fe	mg/kg	1		
Chrome	Cr	mg/kg	0		
Tin	Sn	mg/kg	0		
Aluminum	Al	mg/kg	0		
Nickel	Ni	mg/kg	0		
Copper	Cu	mg/kg	0		
Lead	Pb	mg/kg	0		
Molybdenum	Mo	mg/kg	0		
Manganese	Mn	mg/kg	0		
PQ index	-		< 25		
CONTAMINATION					
Silicon	Si	mg/kg	2		
Potassium	K	mg/kg	0		
Sodium	Na	mg/kg	0		
Water K. F.		ppm	983		
OIL CONDITION					
Viscosity at 40°C	mm ² /s		34.81		
Viscosity at 100°C	mm ² /s		7.17		
Viscosity index	-		175		
Oxidation	A/cm		-		
Color	Color Index		1.0		
ADDITIVES					
Calcium	Ca	mg/kg	0		
Magnesium	Mg	mg/kg	0		
Boron	B	mg/kg	0		
Zinc	Zn	mg/kg	0		
Phosphorus	P	mg/kg	0		
Barium	Ba	mg/kg	0		
Sulphur	S	mg/kg	29		
ADDITIONAL TESTS					
AN / NN	mg/KOH/g		< 0.01		

Description of standards and test methods: www.oelcheck.comScan QR code
Send new sample

LAB REPORT

Unit ID **QSCCB-18-C01-TEST**
 Component **Compressor**
 Current sample number **2816163**



Kerschelweg 28 · 81098 Brannenburg · Germany
 Tel. +49 8034-9047-0 · info@oelcheck.de



page 2 of 3

CERN
 Site de Meyrin
 1211 GENÈVE 23
 SCHWEIZ

Model: **Pas indiqu **
 Manufacturer: **KAESER**
 Sample from: **Gas compressor**
 Oil brand name: **Breox B 35**
 Oil quantity in system: **400 l**

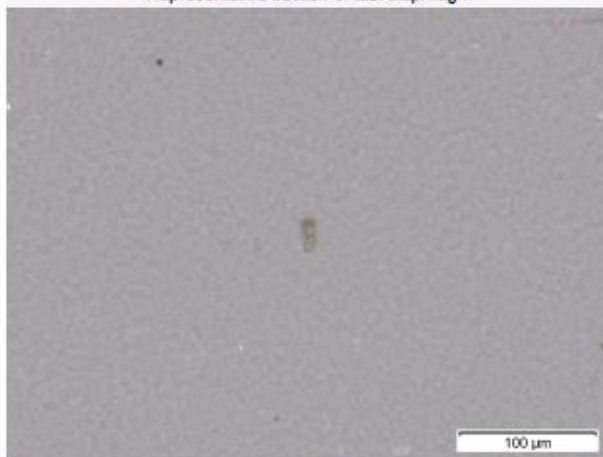
Sample related to: **Test pr levement sortie HP compresseur**

Diagnosis of microscopic particle analysis

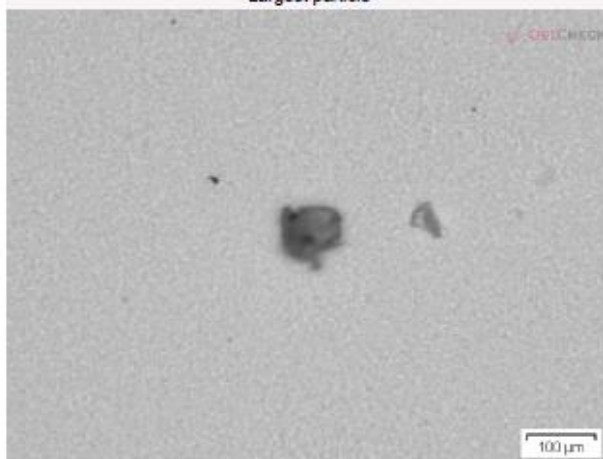
The cleanliness class of the oil complies with the requirements.

Dipl.-Ing. (FH) Klaus Turnwald

Representative section of test diaphragm



Largest particle



ANALYSIS RESULTS

LAB NUMBER	Current sample
Date tested	2816163
Date of sample taken	25.06.2015
Date of last oil change	22.06.2015
Top-up since change	-
Operating time since change	-
Total operating time	-
Oil changed	-

Olympus particle analysis

Cleanliness class	ISO 4406 (1999)	-/16/14
> 5 µm	Particles/100ml	58475
> 15 µm	Particles/100ml	14467

Testing membrane



Description of standards and test methods: www.oelcheck.com

Scan QR code
 Send new sample



LAB REPORT

Unit ID **QSCCB-18-C01-TEST**
 Component **Compressor**
 Current sample number **2816163**



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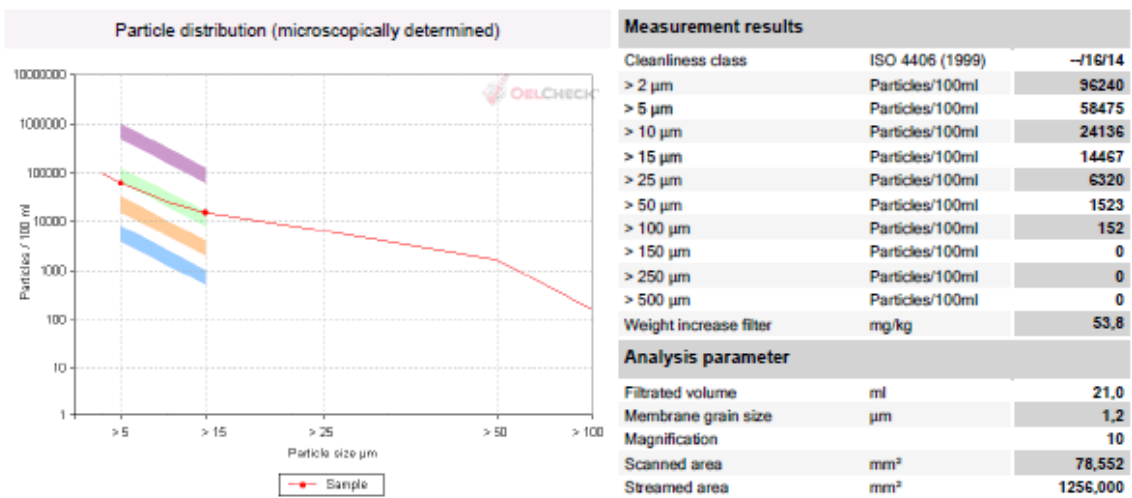
page 3 of 3

CERN
 Site de Meyrin
 1211 GENÈVE 23
 SCHWEIZ

Model: **Pas Indiqué**
 Manufacturer: **KAESER**
 Sample from: **Gas compressor**
 Oil brand name: **Breox B 35**
 Oil quantity in system: **400 l**

Sample related to: **Test prélèvement sortie HP compresseur**

Detailed information for microscopic particle analysis



Typical cleanliness classes

- Planetary- / and spur gears
- Plain Bearings in turbine systems
- Prop valve hydraulic /Rolling bearing paper machines
- Servo valve hydraulic



Description of standards and test methods: www.oelcheck.com

Scan QR code
 Send new sample



D. Procedures for oil sampling

Old sampling procedure [52]

Bringing service to life



Instruction de Travail – Prélèvement d'huile pour analyse

Titre:	Prélèvement d'huile pour analyse
Activité:	Contrat C199
But:	Effectuer un prélèvement d'huile sur une station de compression, expédier le prélèvement pour analyse auprès d'un laboratoire.
Champ d'application:	Technicien mécanicien
Référence:	SJL-C199-WI-034
Version:	1.0
Date:	26/05/2011
Auteur:	Miche CUGNET
Approuvé par:	Tahar KLABI

Condition(s) préalable(s)

Afin d'effectuer cette tâche le technicien doit se munir :

- d'un permis de travail dûment complété et signé conjointement avec l'opération,
- de l'outillage adapté,
- des équipements de protection individuels standards et spécifiques qui sont précisés dans l'instruction de travail,
- du PID de l'installation.

Il doit également s'assurer de la création des Works Orders (WO).

Instruction

1. Principe

Les prélèvements d'huile sont réalisés en point bas des séparateurs d'huile HP (Haute Pression) sur les stations de compression.

Une purge de 5 litres d'huile environ est réalisée avant le prélèvement afin d'évacuer l'huile stockée et d'éviter de collecter les particules éventuelles accumulées en point bas.

Le flacon de prélèvement doit être refermé aussitôt après l'avoir rempli, pour limiter le temps de contact avec l'air et l'humidité ambiante.

2. Risques

Le risque principal est celui lié à la pression et à la projection d'huile.

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Ver: 1.0
Date: 26/05/2011

Sécurité: Interne

1 of 8

3. Préparation

- 3.1. S'assurer avec l'équipe d'opération que le prélèvement d'huile est autorisé :
- Si l'installation est en fonctionnement, le niveau d'huile du séparateur doit être suffisant pour permettre une vidange de quelques litres sans risquer d'atteindre le niveau bas d'arrêt.
 - Une vigilance particulière est à apporter sur les installations qui ont un petit volume d'huile dans le séparateur, à savoir :
 - les stations de compression QSCCA et QSCCB (Kaeser et Mycom),
 - les compresseurs Kaeser du CRYOLAB, du SW18 et de l'ANRS P1.
- 3.2. Sortir du magasin un Kit de prélèvement d'huile avec son flacon. Le code magasin est Q06591.
- Les kits prépayés fournis par le laboratoire OELCHECK comprennent un flacon de prélèvement et une fiche d'identification de l'échantillon « sample information form » munie d'un code barre.
 - Les fiches d'identification vierges sont disponibles au bureau Serco C199 dans le classeur « Analyse d'huile OELCHECK ».
- 3.3. Préparer les EPI spécifiques suivant :
- gants en nitrile
 - masque intégral à cartouche
 - lunettes de protection
- 3.4. Préparer les outillages spécifiques suivant :
- chiffons
 - entonnoir
 - bac en plastique 20 litres
 - film plastique de protection
- 3.5. Imprimer un exemplaire du formulaire SJL-C199-FO-036 « check-list prélèvement d'un échantillon d'huile ».

4. Réalisation

4.1. Prélèvement sur le terrain

- Se faire délivrer un permis de travail par l'opération.
- S'assurer de la localisation précise du point de collecte sous le séparateur d'huile. Pour cela se référer au PID de l'installation. Des exemples des circuits des séparateurs d'huile représentatifs de la majorité des installations sont représentés à titre informatif dans les documents liés.
- Revêtir les EPI spécifiques spécifiés au § 3.3.
- Mettre en place le film plastique de protection pour éviter les projections d'huile.
- Mettre en place le bac sous l'orifice de vidange pour la purge des points bas.
- S'assurer que la vanne de prélèvement est fermée.
- Déposer la bride ou le bouchon d'obstruction.
- Ouvrir doucement la ou les vannes de prélèvement (cas de plusieurs vannes en série).
- Laisser s'écouler 5 litres d'huile environ (pour évacuation du fond d'huile du séparateur).
- Faire le prélèvement dans le flacon d'analyse et le fermer immédiatement.
- Fermer la ou les vannes de vidange.
- Remettre en place la bride ou le bouchon d'obstruction.
- Nettoyer la zone et vider l'huile purgée dans les fûts d'huile usagée disponibles sur site.
- Renseigner le formulaire SJL-C199-FO-036 « Check-list Prélèvement d'échantillon d'huile »
- Identifier l'échantillon prélevé avec la date, le type d'huile et le code d'équipement.

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4.2. Traitement de l'échantillon prélevé

- Enregistrer l'échantillon sur le site Web du laboratoire d'analyse OELCHECK en se connectant à l'URL : <https://www.laborberichte.com/>
- S'identifier avec le login et password.
- Enregistrer le nouvel échantillon en suivant les instructions.
 - Utiliser un nouveau numéro d'échantillon, correspondant à celui de la fiche d'information « sample information form » munie de son code barre disponible dans le classeur « Analyse d'huile OELCHECK ».
 - En cas d'enregistrement d'un nouvel équipement, veillez particulièrement à respecter le code d'équipement et les informations détaillées de l'équipement.
- Imprimer la « fiche de données de l'échantillon » une fois renseignée et enregistrée sur le site OELCHECK et l'archiver dans le classeur « Analyse d'huile OELCHECK ».
- Coller l'étiquette code barre sur le récipient de l'échantillon.
- Faire expédier l'échantillon au laboratoire OELCHECK par les magasiniers, qui procéderont à une demande d'expédition par EDH.

4.3. Résultats d'analyse

- Les analyses sont réalisées par le laboratoire OELCHECK avec un délai moyen de 3 jours ouvrés après réception de l'échantillon.
- Le rapport d'analyse est disponible sur le site WEB du laboratoire et est transmis par courrier électronique.
- A réception du rapport d'analyse :
 - L'enregistrer sur le serveur Sero : \Sero\MaintenanceMecanique & Vide\Analyses d'huile
 - Faire également un enregistrement sur le serveur CERN MM : <https://dfs.cern.ch/dfs/Departments/TE/Groups/CRG/Sections/MM/1%20-%20Technical%20doc/7%20-%20Maintenance%20Follow-up/2%20-%20Reports/2%20-%20Oil%20analysis>
- Renseigner le WO en indiquant la localisation du rapport sur le serveur MM.

5. Enregistrement

La check-list dûment renseignée est numérisée puis archivée sur le serveur Serco C199 : \Sero\Maintenance\Mecanique & Vide\Analyses d'huile.

Documents liés

- SJL-C199-FO-036 « Check-List Prélèvement d'échantillon d'huile ».
- Détails des PIDs des séparateurs d'huile des stations de compression :

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3 of 8

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Ver: 1.0
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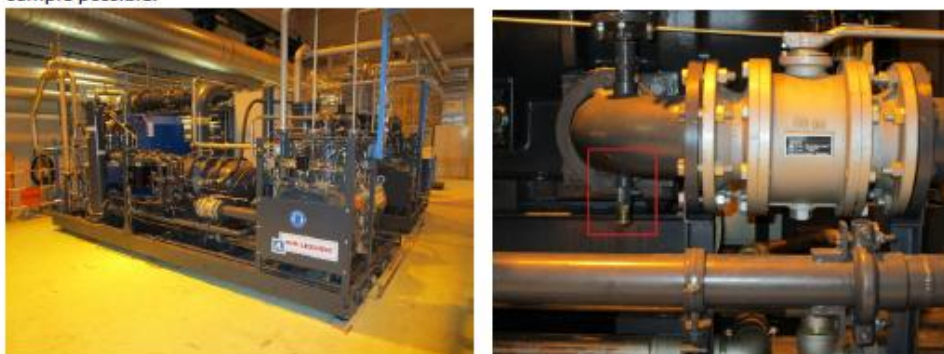
Procedure Oil sampling on Kaeser HSDV760 (QSCCB-18)

1. Sampling goal

The goal of this oil sample is to check both oil condition, machine condition and for contamination. This procedure is a step-by-step instruction on how to carry out oil analysis on the Kaeser HSDV760 compressor in point 1.8. If followed correctly, an oil sample that is representative of the condition of the system and oil will be taken.

2. Sampling location

The sampling spot is located in the return line of the system, between the discharge port and the oil separator. Since this is in an elbow there will be a turbulent flow, giving the most representative sample possible.



The sample will be taken from the valve identified by the tag '1HV122'.



3. Sampling frequency

A sample will be taken every month to maximize the information gathered concerning the system. A more frequent sampling gives a better view on the critical condition of the oil and machine. The scheduling for work order of the sampling will be done by the TE-CRG-ME section.

4. Material requirements

4.1. Safety equipment

- Nitrile gloves
- Protective mask
- Protective glasses
- Hearing protection

4.2. Work equipment

- Oilcheck sampling kit (Containing a glass sample bottle and identification code)
- Clean tubing
- Cloths
- Funnel with attachment for valve
- Plastic tray
- Plastic protective foil

5. Sampling method

1. Locate the valve at the bottom of the return line in de elbow identified by the tag (1HV122).



2. Equip the safety equipment.



3. Lay out the plastic protective foil to prevent the oil from staining the surroundings.
4. Place the plastic tray under the valve.

5. Insert the hose in the valve



6. Gently open the valve.
7. Drain about 5 litres of oil into the plastic tray (to clear the oil from the sediment and particles collected at the valve).



8. Let the oil flow into the provided glass bottle until it is filled up and close it immediately.
9. Close the valve.
10. Pour the oil that flowed into the plastic tray into the used oil drums on the site.



11. Clean the area.
12. Mark the bottle with the date, oil type and identification code.

6. Potential Source of Interference

- Check label of the valve and make sure it says "1HV122"
- Make sure the sample bottle stays closed until right before you take the sample and close it immediately after

7. Safety considerations

- Since the oil is under pressure and hot, there is a chance of the oil being sprayed around and burn the technician. To prevent this, make sure the PPE (Personal Protective Equipment) is adequate and equipped.
- Make sure there are no safety risks in the environment and do not get distracted while taking the sample.

E. Thresholds and categories of issue

Thresholds Oil analysis parameters

WEAR	Limits		
	Normal	Issue	Major Issue
Iron (Fe) → ppm	5	10	15
Tin (Sn) → ppm	10	15	20
Aluminium (Al) → ppm	5	10	15
Lead (Pb) → ppm	15	20	25
PQ index	Previous sample	+10%	+15%
Copper (Cu) → ppm	15	20	25
Chrome (Cr) → ppm	5	10	15
Nickel (Ni) → ppm	5	10	15
Manganese (Mn) → ppm	10	15	20
Molybdenum (Mo) → ppm	5	10	15

OIL CONDITION	Limits		
	Normal	Issue	Major Issue
Viscosity 40°C / 100°C → cSt	Base value +20% / -10%	Base value +25% / -15%	Base value +30% / -20%
Silicon (Si) → ppm	15	20	25
Acid Number (AN) → mgKOH/g	0.5	0.75	1
Oxidation	-	-	-

CONTAMINATION	Limits		
	Normal	Issue	Major Issue
Cleanliness class	19/17/13	20/18/14	22/20/16
Water	600	600-1200	1200+
Potassium (K)	10	15	20
Sodium (Na)	10	15	20
Tungsten (W)	10	15	20



ADDITIVES	Limits		
	Normal	Issue	Major Issue
Zinc (Zn) → ppm	5	10	15
Sulphur (S) → ppm	5	10	15
Calcium (Ca) → ppm	5	10	15
Magnesium (Mg) → ppm	5	10	15
Boron (B)	5	10	15
Phosphorus (P)	5	10	15
Barium (Ba)	5	10	15

F. Classes of impact of key parameters and possible causes

Classes of impact of Key parameters and their possible causes

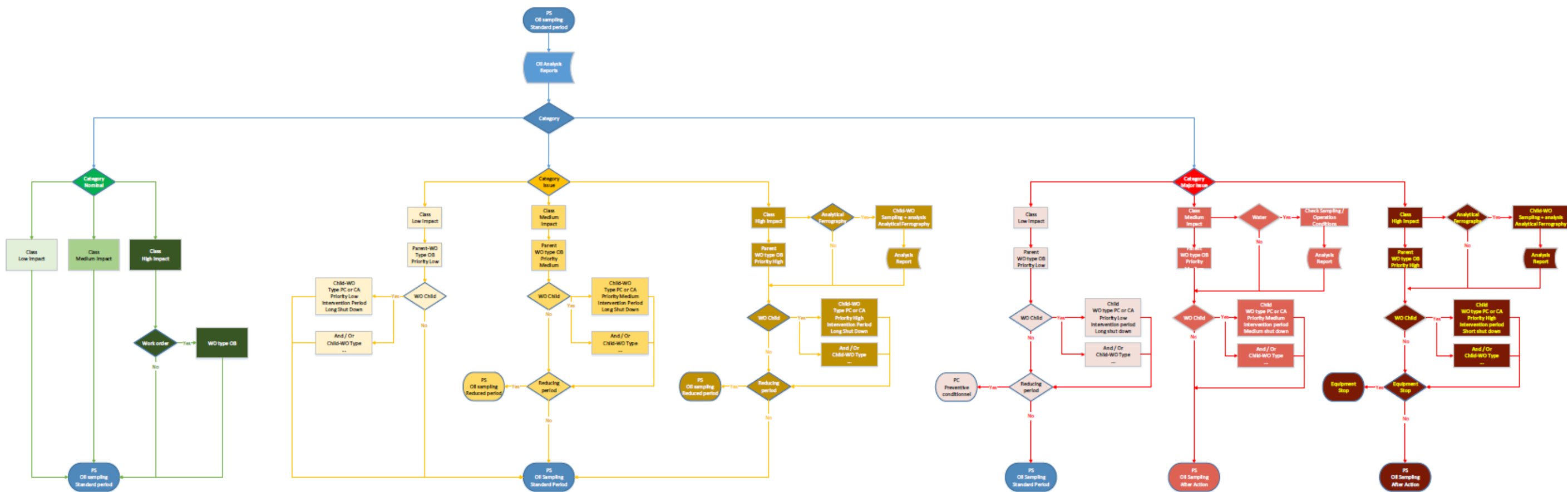
High Impact	
Wear metals	
Iron (Fe)	Bearings, Screws, Housing
Tin (Sn)	Bearings, Bushings, Solder
Aluminium (Al)	Housing, Screws
Lead (Pb)	Bearings, Bushings, Solder
Chrome (Cr)	Bearings, Shafts
Nickel (Ni)	Bearings, Shafts
Copper (Cu)	Bearings, Bushings, Thrust Plate, Oil Cooler Tubing
PQ index	Wear metals
Oil condition	
Viscosity 40°C	Oxidation, thermal degradation, mixing with other oil, ...
Contamination	
Cleanliness class	High amount of particles

Medium Impact	
Oil condition	
Silicon (Si)	Dust, Silicon based synthetics, Sealants
Acid Number (AN)	Deteriorating oil, additives
Contamination	
Water	

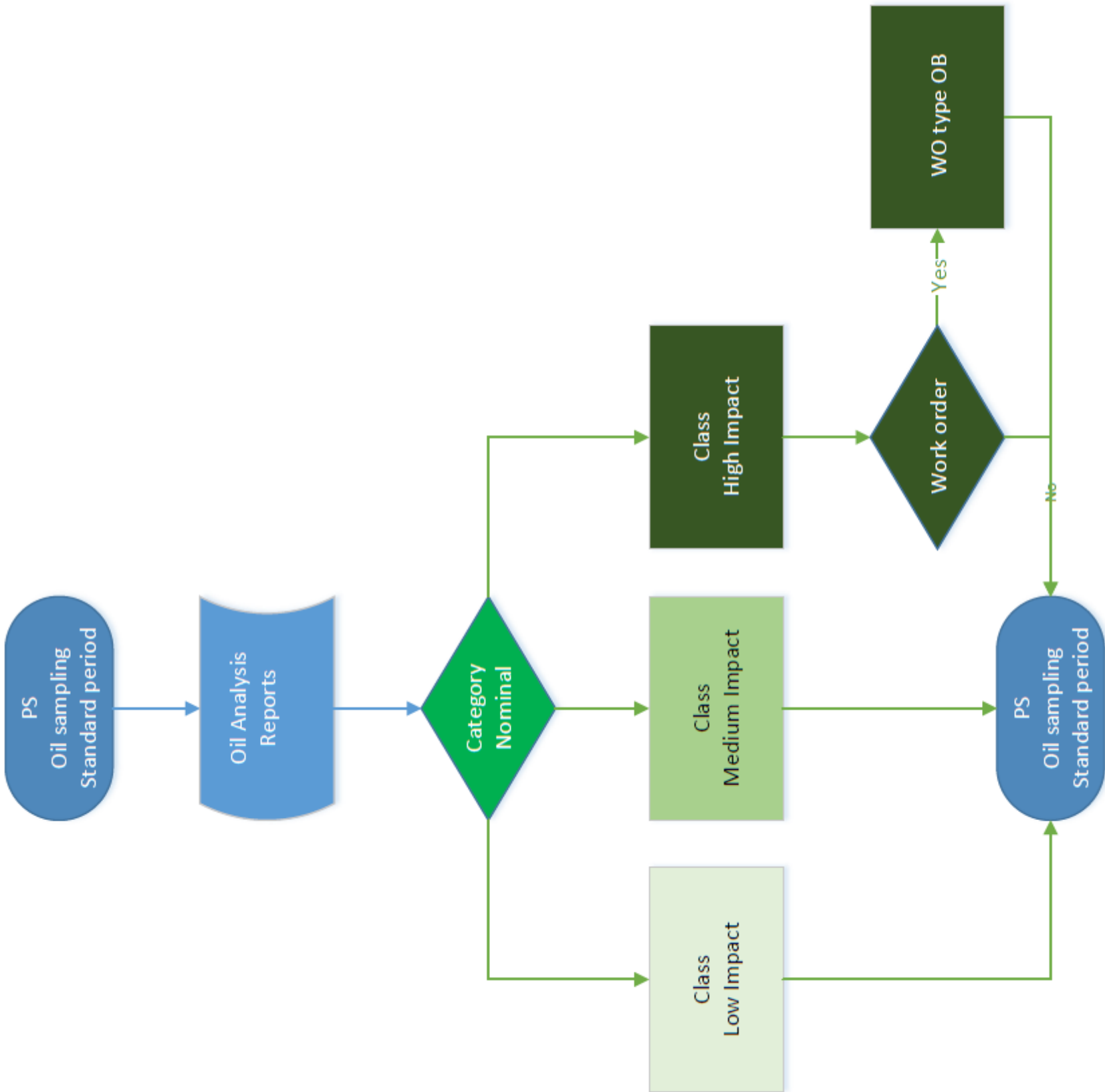
Low Impact	
Wear metals	
Manganese (Mn)	Shafts
Molybdenum (Mo)	Alloy or Plating from Rings, Retainer Pins, Friction Modifier Additive in Oils, Grease Contamination, <u>Molybdates</u> from Some Coolants
Oil condition	
Oxidation	
Contamination	
Potassium (K)	Water Contaminant, Anti-Freeze Inhibitor
Sodium (Na)	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor
Tungsten (W)	
Additives	
Zinc (Zn)	Alloy in Brass, Anti-Wear Additive ZDDP, Galvanized Steel from Filter Canisters
Sulphur (S)	
Calcium (Ca)	Detergent/Dispersant Additive, Calcium from Water Contamination, Lime Dust
Magnesium (Mg)	Detergent/Dispersant Additive, Alloy, Environmental Contaminant
Boron (B)	Additive Common in Engine Oils, Some Gear Oils
Phosphorus (P)	EP Additive, Anti-Wear Additive ZDDP(<u>Zinc-DialkylDithioPhosphate</u>), Phosphate Ester, Phosphate Inhibitor found in Coolants

G. Decision trees

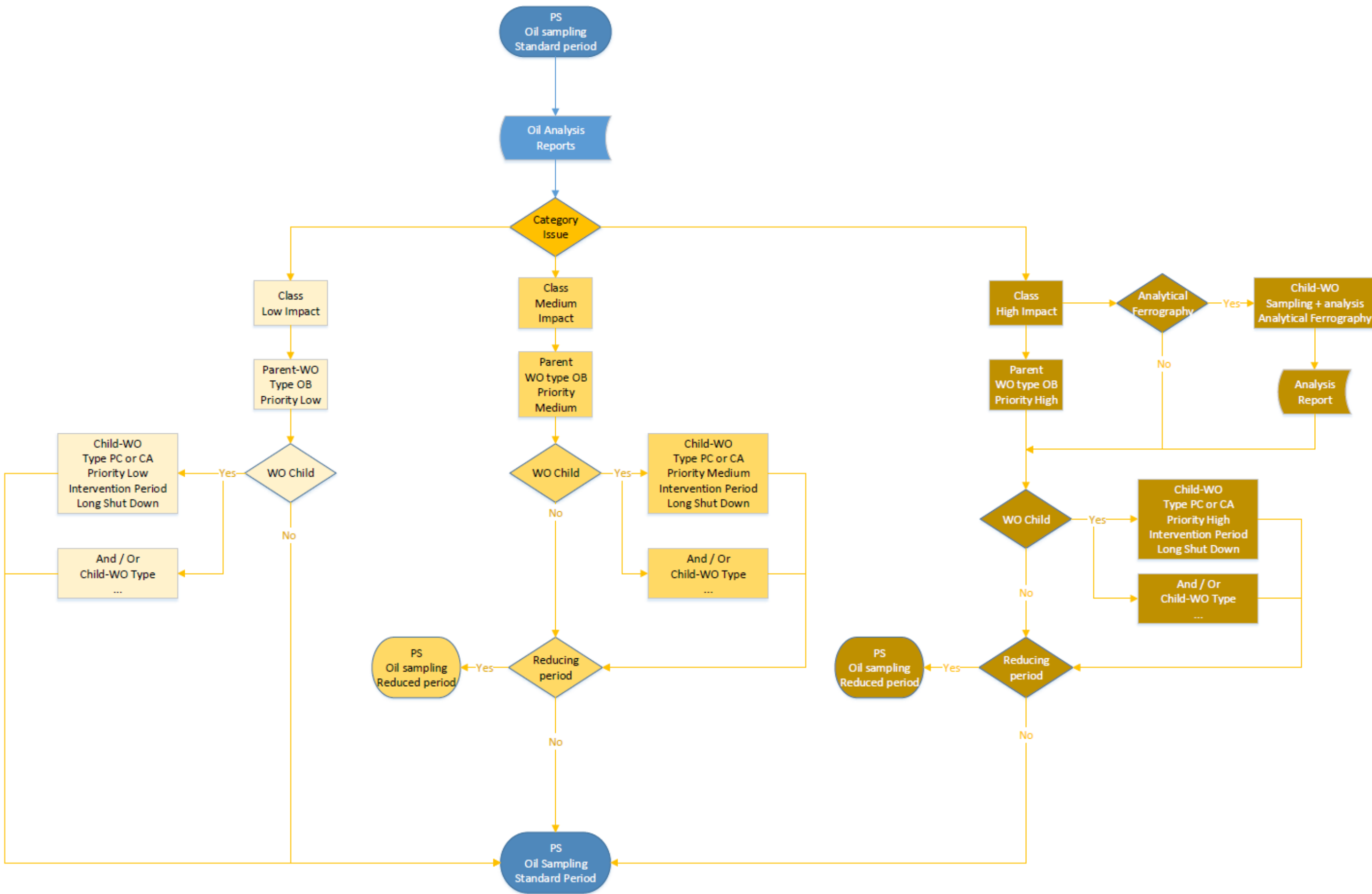
Combined Decision Tree



Category "Normal" Decision Tree



Category "Issue" Decision Tree



Category "Major Issue" Decision Tree

