WEBINAR 2021

Successful Use of Latest Benchtop XRF Technology for Better Lubricants

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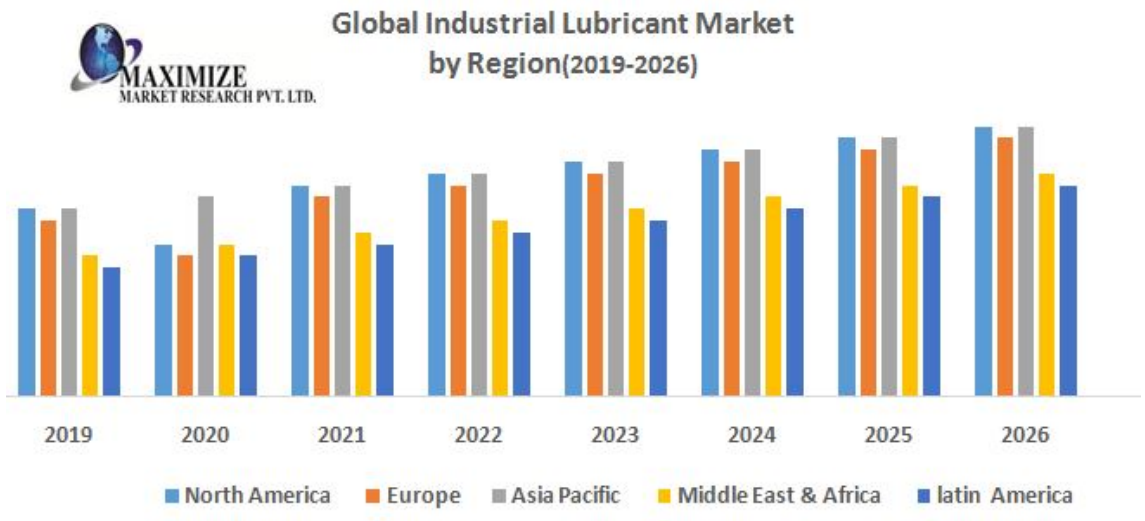
Outline

Global Markets on Lubricants

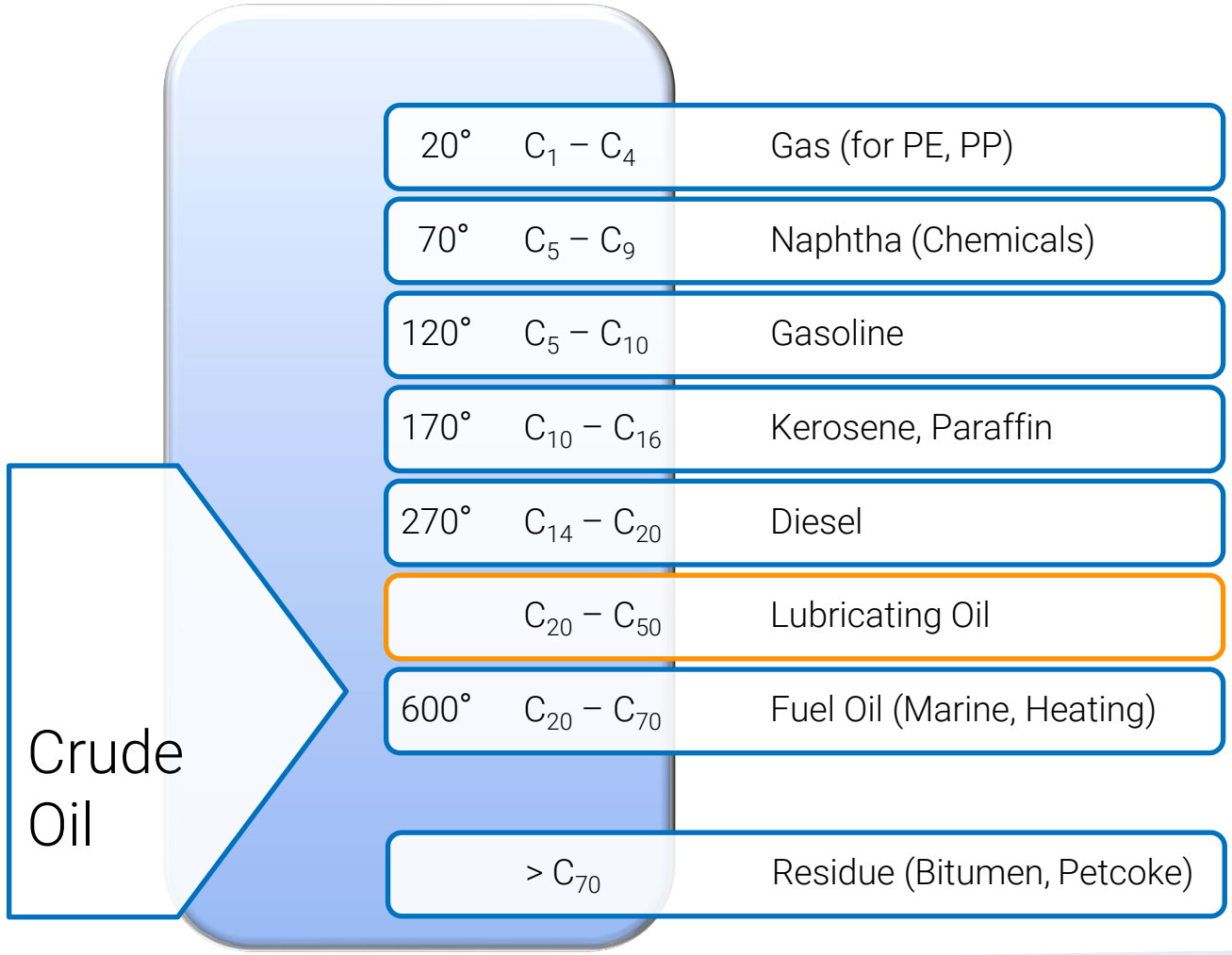


New application fields for lubricants (wind energy, electric mobility) and development of southern regions (personal mobility, investments in machinery) are drivers for the lubricant market.

- Lubricants are essential on small scale: Reducing friction and wear significantly enhances engine lifetime and reduces cost of operation of machinery
- Lubricants are a big business on global scale: small amounts, continuous use are adding up to an enormous demand
- Lubricants are special: modern formulation are enhancing technology changes: new lubricants are required for electric vehicles, reducing fuel consumption of traditional car engines, enhancing uptime of wind turbines and enabling new technologies (DSG dual clutch gears)
- Lubricants are generalists and specialists!

Source: www.maximizemarketresearch.com/market-report/global-industrial-lubricant-market/15207/

Oil Refinery Products



A lubricant is a substance introduced between two moving surfaces to reduce the friction between them, improving efficiency and reducing wear. It may also have the function of dissolving or transporting foreign particles and of distributing heat. Typically, lubricants contain 90% base oil (most often petroleum fractions, called mineral oils) and less than 10% additives. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging or contamination, etc.

Lubricants

Substances that reduce the friction between surfaces in mutual contact

- Liquid lubricants
  - Based on mineral oil (bicycles, old combustion engines, industrial engines with high demand of oil)
  - Based on synthetic oils (specific use with specialized formula: new combustion engines for reduced fuel consumption, gear box oil for wind turbines)
- Solid lubricants
  - Grease
- Use of additives to modify properties and to enhance performance

Lubricants and its Functions

- Keep moving parts apart, reduce friction, protect against wear
  - Establish a stable film on the material surface
  - Stabilize this film under operating conditions
- Transfer heat
  - Cool engine parts and transport heat to an external cooler (bearings, metal working fluids, combustion engines)
- Carry away contaminants and debris
  - Neutralize traces of water
  - Bind particles and transport them safely to the engine filter
- Prevent corrosion
  - Cover fresh metal surfaces (in case of frictions, metal working)

Applications of XRF in Quality Control for Lubricants

- Additives are expensive, but typically contains at least one tracer element, which can be used to control the concentration to be within the specification
  - Mg and Ca containing soaps
  - S in sulfonates
  - Mo compounds

XRF is used for…

- Quality control in base oil production
- QC of blending operations of lubricants
- Monitoring of additives, at additive manufactures and dosing stations
- Lubricating oil analysis at automotive manufacturers and its suppliers

- Failure analysis: Wear metal analysis in engine test stands, at automotive manufacturers and its suppliers

Standards and Applications of XRF for Lubricants

- EN ISO 14596 Low S
- EN ISO 14596 High S
- EN ISO 14597 V and Ni
- EN ISO 15597 Cl and Br
- ASTM D 6443 Ca, Cl, Cu, Mg, P, S and Zn
- DIN 51790 S, V and Ni
- DIN 51363 P
- DIN 51391 Zn and Ca
- DIN 51431 Mg

How does current Petrochemical Element Analysis often looks like?

Atomic Absorption Spectrometry (AAS)

- Sample must be prepared/diluted
- Requires daily instrument calibration
- Requires gases for flame or graphite tubes
- Usually, single element analysis

Inductively Coupled Plasma Spectrometry (ICP-OES)

- Similar to AAS
- Requires expensive Argon gas for plasma
- Requires adjustment of plasma gas conditions

UV/VIS Spectroscopy (UV)

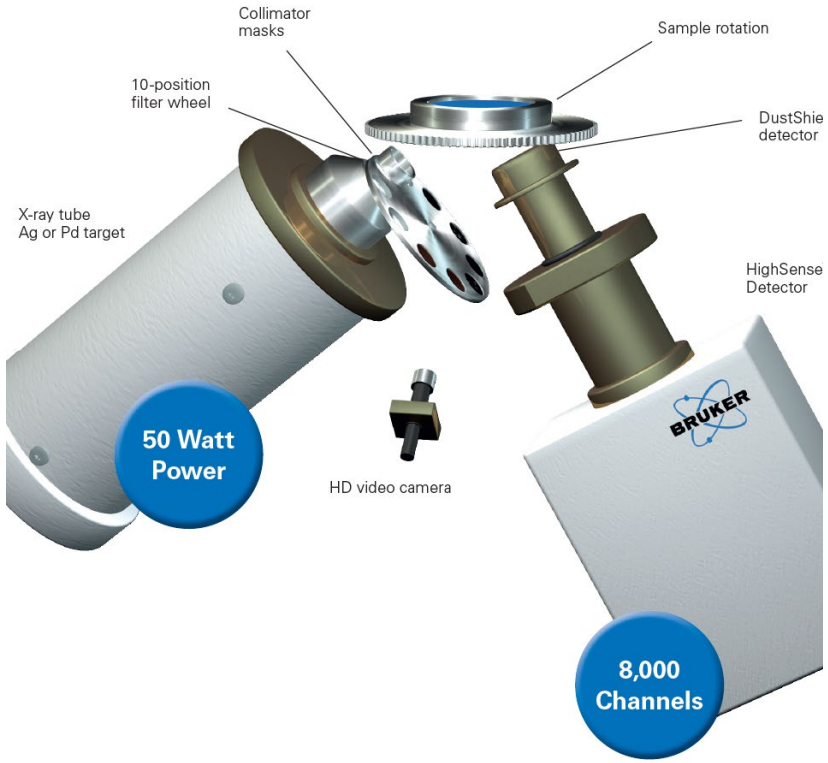
- Requires reagents for UV reaction

Sample Preparation in XRF
Easy and straight forward

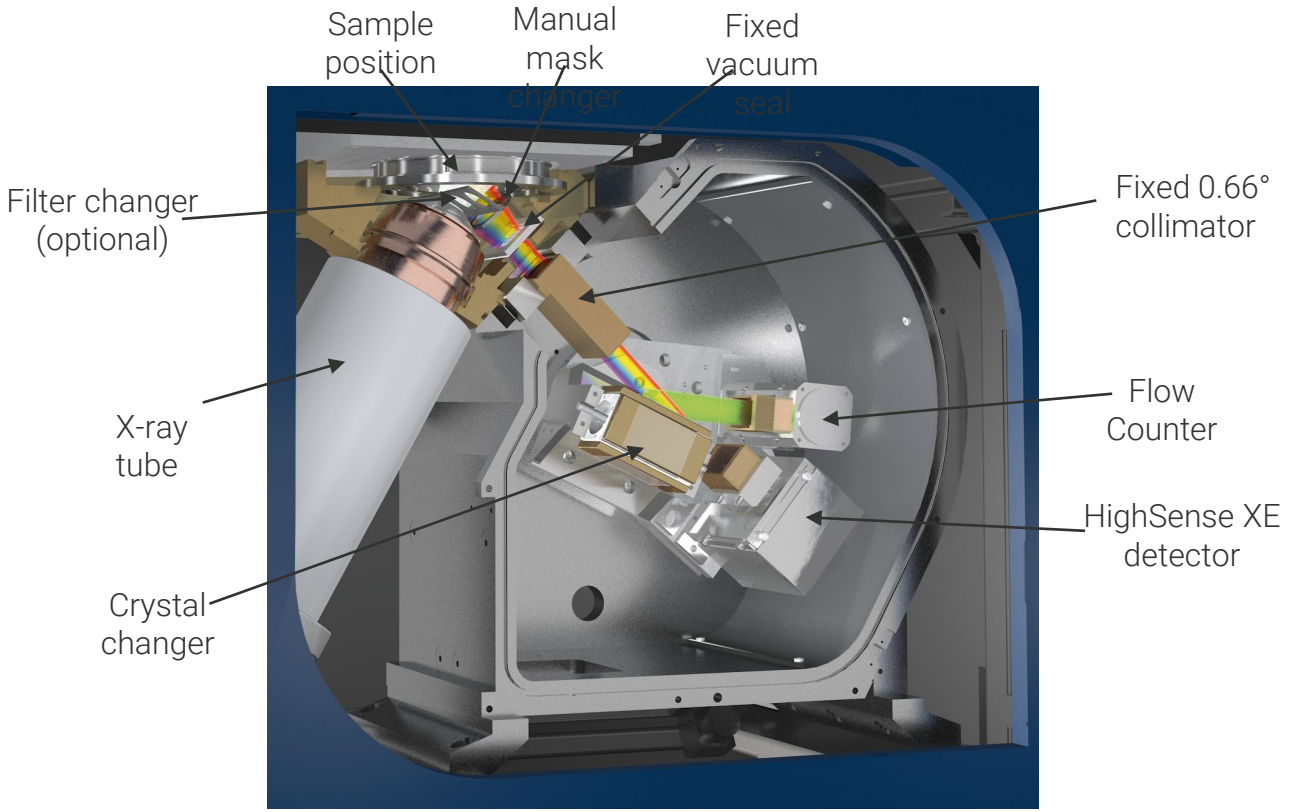
- First step: **Prepare the sample cup**
- Second step: **Fill the sample cup**
- Place the cup on the balance
- Fill with approx. 7 g of sample
- Third step: **Load the sample**
- Place the cup in the chamber of the instrument
- Done! **No dilution, no digestion!**
- **Low costs of ownership with standard liquid cups!**

Energy-Dispersive XRF (EDXRF) vs. Wavelength-Dispersive XRF (WDXRF)

EDXRF



WDXRF



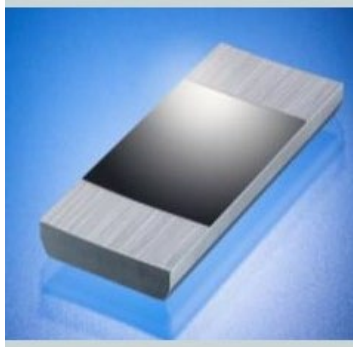
X-ray Fluorescence Analysis (XRF)
The Comparison of Energy and Wavelength Dispersive Spectrometers

EDXRF

- Mechanical simplicity
- Cheaper
- Sensitivities: down to the ppm level
- Easy operation
- Smaller, “can be brought to the sample”

WDXRF

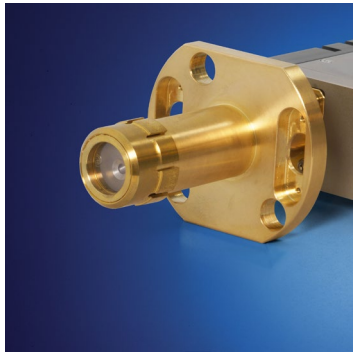
- High precision mechanics
- Higher capital
- Precision: <0.05%
- Higher resolution
- Sensitivities: down to the ppm level, but roughly one to two orders more sensitive
- Very fast analysis
- Highest sample throughput

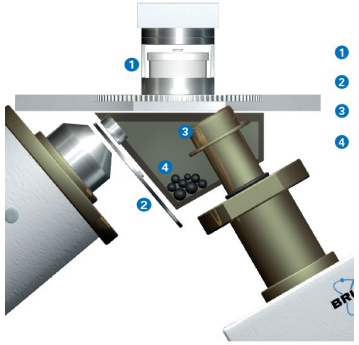



S2 PUMA Series 2
A versatile Benchtop EDXRF for multiple Petrochemical Tasks

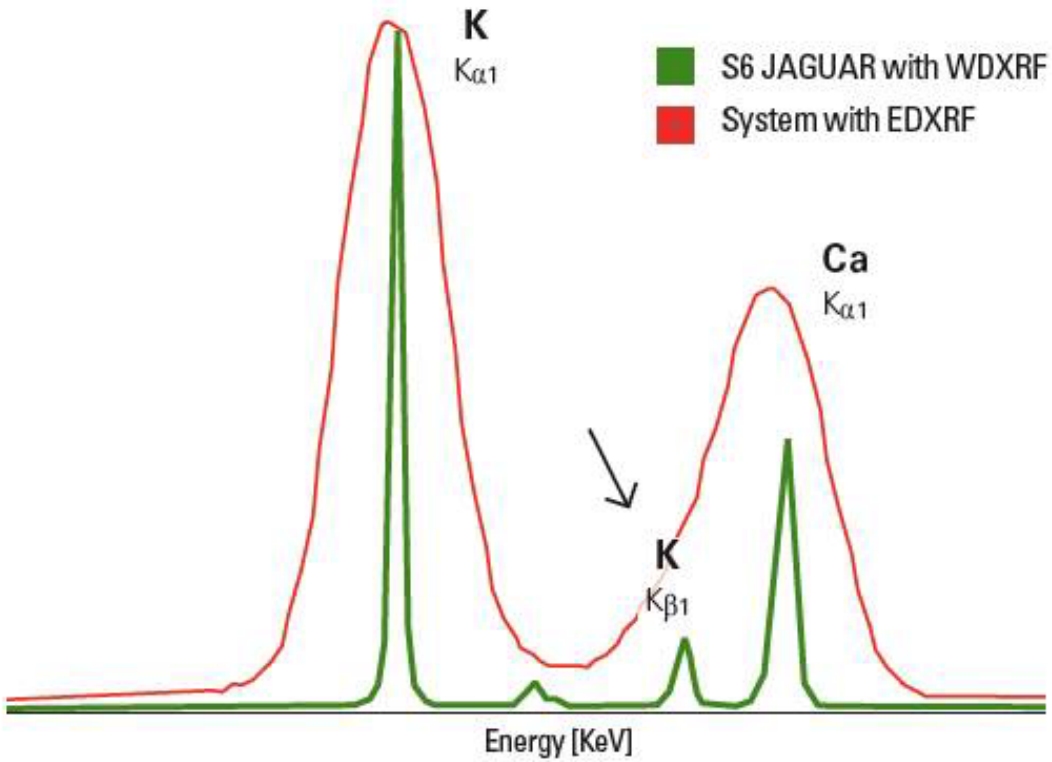
- High-performance EDXRF spectrometer with 50 W X-ray tube
- Direct excitation
- HighSense detector technology
- SampleCare™ including liquid cup detection

- Additives in lubricants
  - Mg, P, S, Cl, Ca, Zn, Mo
  - Norms ASTM D6481, D7751
- Wear metals in lubricants
  - Few ppm of e.g., Cr, Cu, Fe, Mo, Ni, V, Zn, …
- Fuels, Gasoline
  - S and Cl down to 1-2 ppm
  - Norms: ASTM D4294, ISO 8754, ISO 20847





S6 JAGUAR
HighSense™ Goniometer: High Resolution



- The S6 JAGUAR with WDXRF HighSense Goniometer excels
- ED based systems in resolution and analytical precision
  - Better peak to background signal ratio
  - Higher intensity (signal in left picture is scaled)
  - Better separation of neighboring signals
  - Better resolution of WDXRF will help to clearly identify elements, esp. traces of wear metals
  - Higher precision, e.g. for light elements, such as Mg, tighter control limits for additives

S6 JAGUAR - Benchtop WDXRF
High Performance Benchtop WDXRF

Configurable from single element analyzer for S to multi-purpose unit for the periodic table

All-new technology and software:

- Long lifetime X-ray tube
- Compact goniometer with high precision gears and closely coupled X-ray beam path
- Optimized analyzer crystals for the entire element range and special applications
- HighSense detection with 2 Mcps countrate
- HighSense XE detector for medium and heavy elements
- SPECTRA.ELEMENTS analytical SW
- SMART-QUANT WD with new FP algorythms

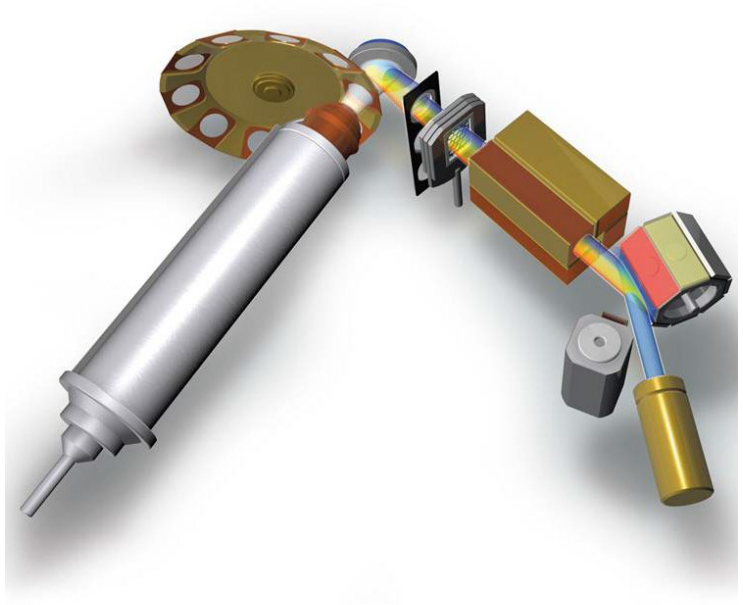
S6 JAGUAR Benchtop WDXRF

400 W excitation

Multi Purpose Sequential WDXRF Spectrometer S8 TIGER for the Central Lab

Analytical flexibility and high performance for sub-ppm traces

- 4 kW excitation
  20 – 60 kV
- 5 – 170 mA
- 10 beam filters
- 4 collimators
- 8 crystals
- 2 detectors



S8 TIGER WDXRF Beam path

Floor standing WDXRF S8 TIGER with 1, 3 or 4 kW

Lubricating Oils Standards Overview

	DIN 51399	ASTM D6443	ASTM D4927	ASTM D7751	ASTM D6481
Applied technique	WDXRF	WDXRF	WDXRF	EDXRF	EDXRF
Title of norm	Determination of Elements Content in Additives, Wear and Other Contaminations	Determination of Ca, Cl, Cu, Mg, P, S, Zn in Unused Lubrication Oils and Additives	Elemental Analysis of Lubricant and Additive Components	Determination of Additive Elements in Lubricating Oils	Determination of Additive Elements in Lubricating Oils
Elements (max. concentrations)	5 - 500 ppm: Na, Al, Si, Cl, K, Cr, Fe, Ni, Cu, Mo, Sn, Ba, Pb 0.01 - 0.1 %: Mg 0.05 - 0.50 %: P, Ca, Zn 0.10 - 2.5 %: S	Ca (0.40 %), Cl (0.20 %), Cu (0.05 %), Mg (0.20 %), P (0.25 %), S (1.00 %), Zn (0.25 %)	Ba (8.5 %), Ca (1.0 %), P (0.5 %), S (4.0 %), Zn (0.6 %)	Mg (0.10 %), P (0.125 %), S (2.0 %), Cl (0.05 %), Ca (0.44 %), Zn (0.14 %), Mo (0.05 %)	P (0.30 %), S (1.00 %), Ca (1.00 %), Zn (0.30 %)
Scope	Additives, wear and other contaminations, incl. used oils	Unused lubrication oils and additives	Unused lubrication oils and additives	Unused lubricating oils and additive packages	Unused lubricating oils and additive packages
Bruker norm compliance	S6 JAGUAR, S8 TIGER	S6 JAGUAR, S8 TIGER	S6 JAGUAR, S8 TIGER	S2 POLAR, S2 PUMA	S2 POLAR, S2 PUMA

Benchtop EDXRF for Petrochemical Applications S2 POLAR

- Quality control in base oil production
- QC of blending operations of lubricants
- Monitoring of additives, at additive manufactures and dosing stations

- Fully norm compliant with ASTM D7751 and D6481
- Small size for small labs, low cost of ownership
- Quick sample preparation w/o any chemicals involved
- Ease-of-use w/ TouchControl for shift workers
- Robust technology w/ little maintenance
- One-time calibration

ASTM D7751-16

Designation: D7751 – 16

Standard Test Method for
Determination of Additive Elements in Lubricating Oils by
EDXRF Analysis[1]

- Determination of **Additive Elements** in Lubricating Oils by **EDXRF**
- Covers additive elements **Mg, P, S, Cl, Ca, Zn, and Mo**
- Defined repeatability (r) and reproducibility (R) limits have to be fulfilled

ASTM D7751 - Repeatability Lubricating Oil Sample S2 POLAR

Passed

	Mg [%]	P [%]	S [%]	Cl [%]	Ca [%]	Zn[%]	Mo [%]
Rep 01	0.099	0.111	0.511	0.027	0.204	0.119	0.010
Rep 02	0.097	0.112	0.514	0.026	0.201	0.120	0.010
Rep 03	0.102	0.111	0.509	0.026	0.202	0.118	0.010
Rep 04	0.101	0.112	0.514	0.026	0.203	0.121	0.010
Rep 05 - 16	...	...	...	...	...	...	...
Rep 17	0.104	0.111	0.512	0.026	0.202	0.118	0.010
Rep 18	0.098	0.111	0.513	0.027	0.202	0.121	0.009
Rep 19	0.101	0.112	0.513	0.026	0.203	0.119	0.009
Rep 20	0.094	0.111	0.511	0.026	0.203	0.119	0.009
Mean value	0.100	0.111	0.512	0.026	0.202	0.119	0.009
Abs. Std. Dev.	0.0025	0.0004	0.0016	0.0001	0.0010	0.0009	0.0002
Rel. Std. Dev.[%]	2.49	0.36	0.31	0.40	0.51	0.78	1.98
Min. [%]	0.094	0.111	0.509	0.026	0.200	0.118	0.009
Max. [%]	0.104	0.112	0.515	0.027	0.204	0.121	0.010
Certified value	0.100	0.110	0.500	0.025	0.200	0.120	0.0100

Benchtop EDXRF for Petrochemical Applications S2 POLAR

- Very small, compact footprint
- For space-saving analysis in labs
- Also important for on-site process control with limited space in refineries, tank terminals, depots
- Ready-to-analyze ‘One Button’ solutions, e.g.
- ASTM D7751, D6481
- ASTM D7220, D4294, ISO 13032
- ASTM D8252, D4929C

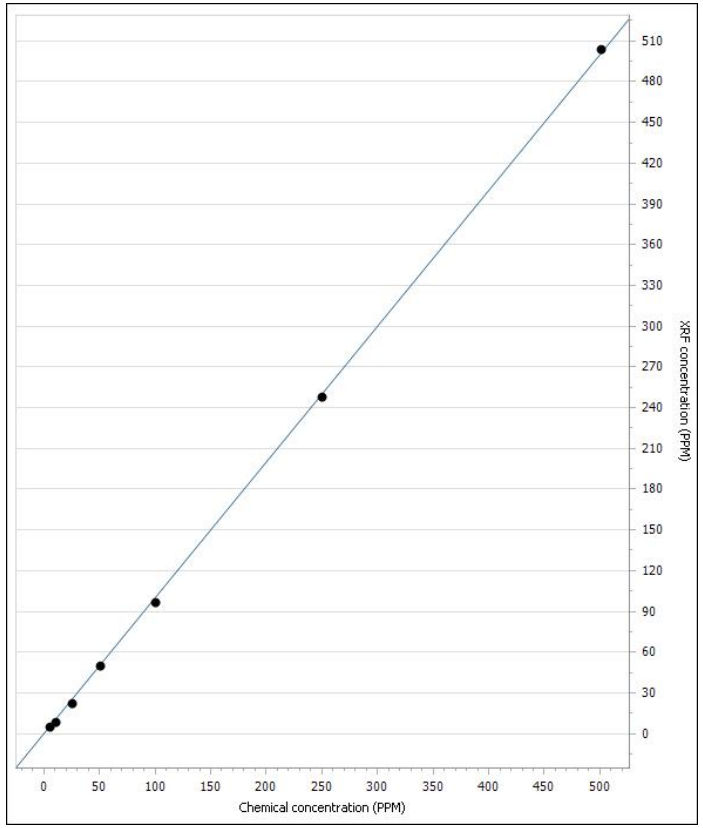
One instrument does it all for refineries:

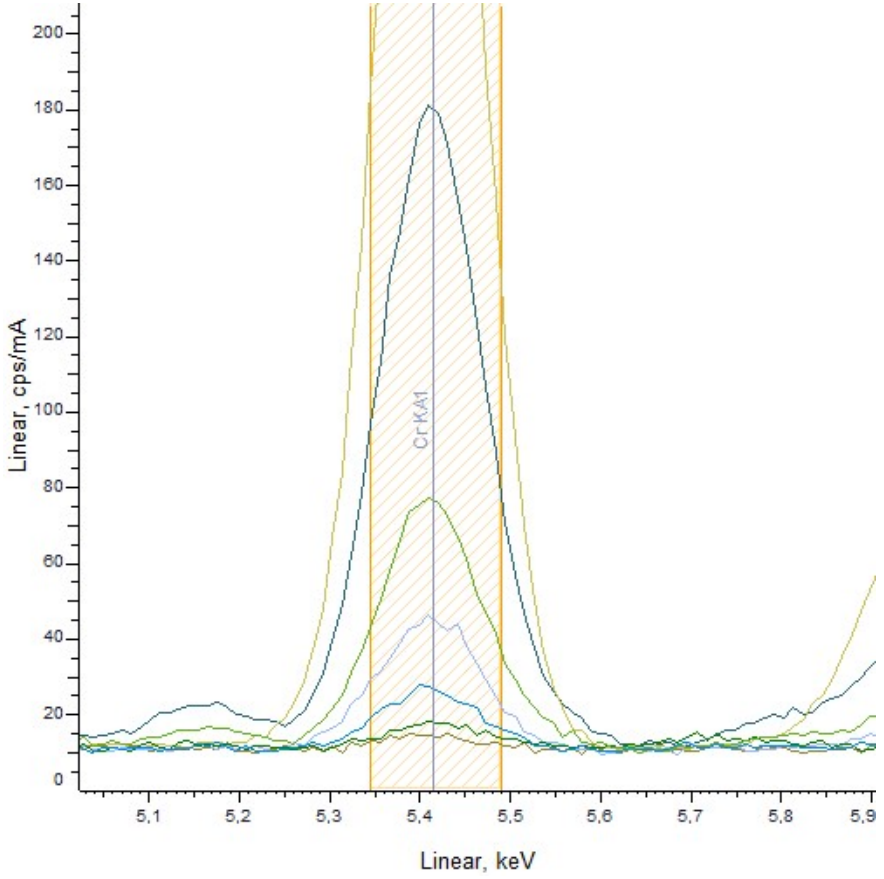
From Ultra-Low Sulfur (ULS) in fuels to % in crudes

Norm-compliant to ASTM D7220, D4294, ISO 13032, 20847, 8754

Wear Metal Analysis
S2 PUMA Series 2

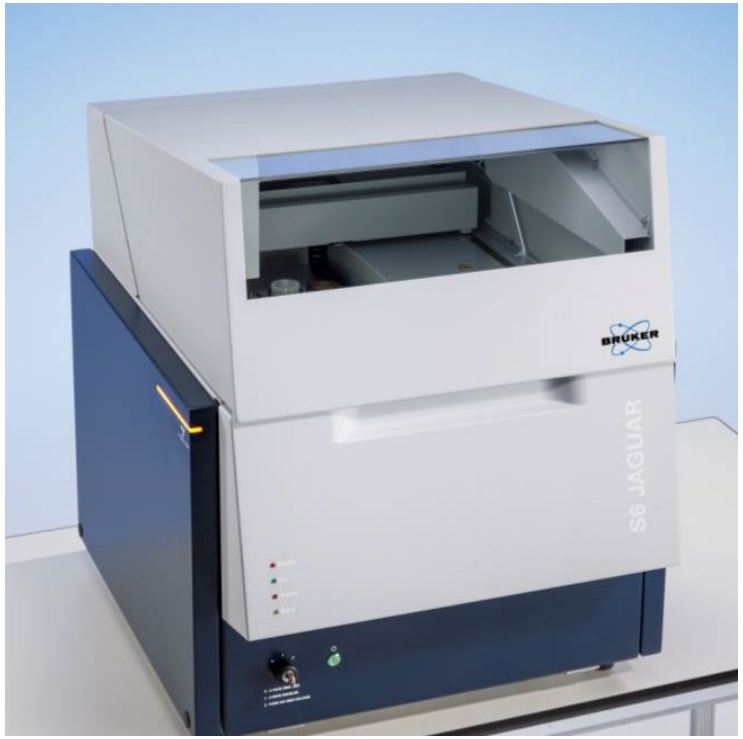
- The direct excitation of the S2 PUMA results in better performance for heavier elements when compared to the S2 POLAR
- Example Mo measured according to ASTM D7751 reveals a ~3 times better precision on the S2 PUMA





Additives and Contaminants in Lubricating Oils – ASTM D6443 S6 JAGUAR

- WDXRF is defined as international standard, delivering best detection limit, robustness and precision
- But limited no of samples and/or applications doesn‘t justify budget for high power, floorstanding units
- Compact mid power instruments, like S6 JAGUAR can be configured from single element units to multi-purpose



Unit w/ Autochanger for higher productivity

Single Loader for immediate analysis

Additives and Contaminants in Lubricating Oils – ASTM D6443 S6 JAGUAR

- Analysis of additives in lubricating oils to ensure proper oil performance
- Acc. ASTM D6443 for Ca, Cl, Cu, Mg, P, S and Zn
- Cost reduction possible with high accurate and precise analysis
- Blending of oils close to specifications
- Cost savings of expensive additives

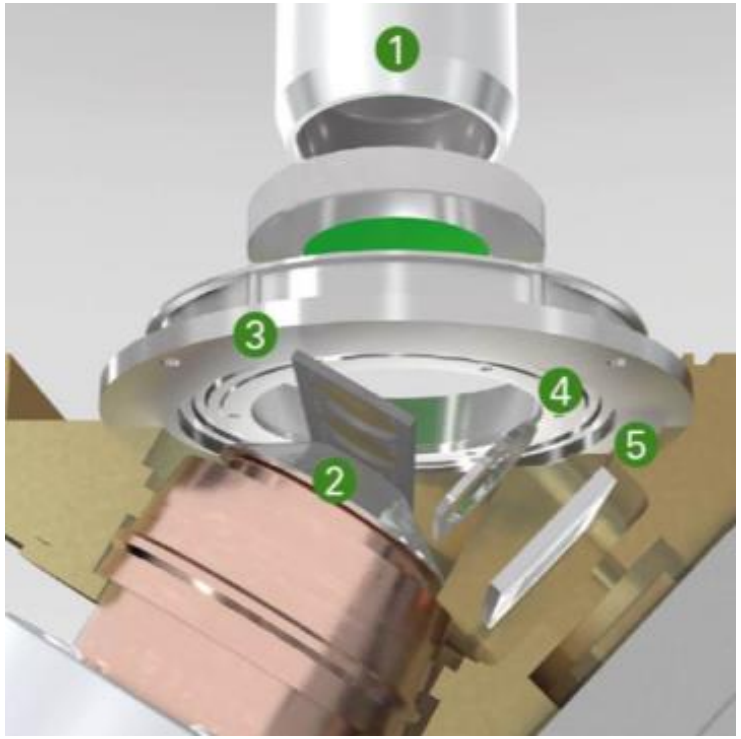
Additives and Contaminants in Lubricating Oils – ASTM D6443 S6 JAGUAR

[wt%]	Mg	P	S	Cl	Ca	Cu	Zn
Rep-1	0.0786	0.0501	0.2781	0.0505	0.2034	0.0203	0.0503
Rep-2	0.0797	0.0513	0.2802	0.0505	0.2039	0.0203	0.0501
Rep-3	0.0780	0.0494	0.2782	0.0501	0.2028	0.0201	0.0501
Rep-4-12	...	...	...	...	...	...	...
Rep-13	0.079	0.0511	0.2789	0.0516	0.2041	0.0199	0.0505
Average	**0.0787**	**0.0501**	**0.2793**	**0.0507**	**0.2037**	**0.0201**	**0.0503**
Abs. Std. Deviation	**0.0006**	**0.0006**	**0.0010**	**0.0004**	**0.0014**	**0.0001**	**0.0001**
ASTM D6443	✓	✓	✓	✓	✓	✓	✓
Rel. Std. Deviation [%]	0.71	1.23	0.37	0.86	0.66	0.70	0.27
Certified value	**0.0800**	**0.0500**	**0.2754**	**0.0500**	**0.2024**	**0.0200**	**0.0501**
Difference	**0.0013**	**0.0001**	**0.0039**	**0.0007**	**0.0013**	**0.0001**	**0.0002**
Rel. Difference [%]	1.62	0.20	1.43	1.40	0.64	0.50	0.38

- Excellent reproducibility and high analytical precision
- Less than 1% rel. per element, light elements about 1% rel., traces at 2 % rel dev.

SampleCare™: High Instrument Uptime & Low Cost of Operation S6 JAGUAR

- High instrument uptime due to unique protection during loading and unloading
- Two contamination shields to protect tube window and goniometer
- Unique Vacuum Seal with high transmission window for goniometer protection
- Low helium consumption
  - Flushing of sample chamber only
  - Goniometer chamber remains in vacuum all the time



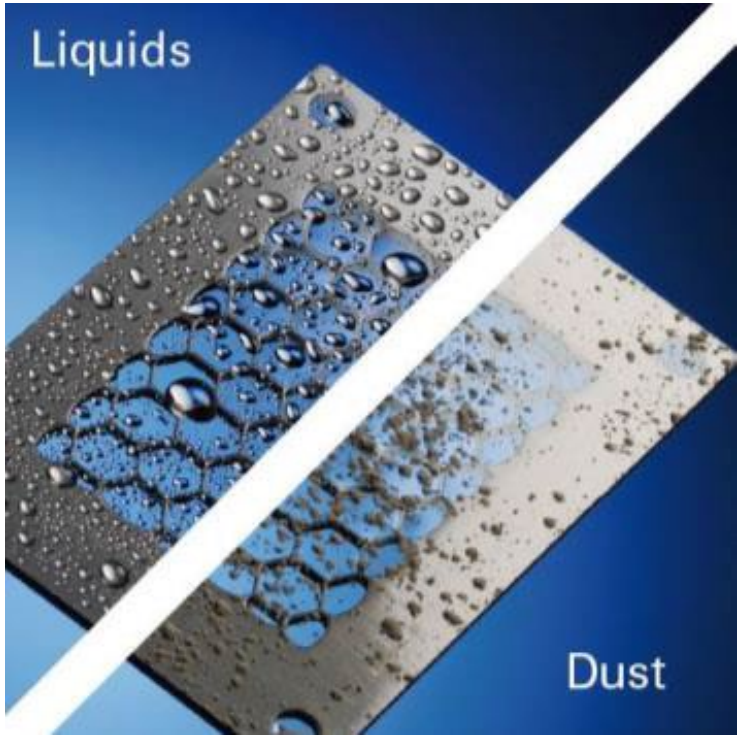
1 Grabber with automatic sample detection

2 Tube shield

3 Filter changer

4 Mask holder

5 Vacuum seal



Unique High Transmission Vacuum Seal

“The S6 JAGUAR WDXRF has become an indispensable tool in our QC lab. The quick analysis of our lubricating products acc. to ASTM D 2622 and D 6443 with low cost of operation is unique. We have recommended the instrument in our company globally”

Additives and Wear Metals in Lubricating Oils with the S8 TIGER Series 2

- High sample load, multiple applications from fuels, oils, coke, catalysts,…
- Precise and close control of low levels possible by WDXRF
- Several calibrations for each matrix with ASTM D…
- Internal standards (EN ISO) for just one method for all matrices
- Enhanced analytical performance with lower COV compared to EDXRF
- Better handling of various matrices, e.g. biofuels, compared to FT-IR, AAS and other methods
- Atmospheric purge vs reduced pressure to enhance analytical performance and reliability for volatile samples

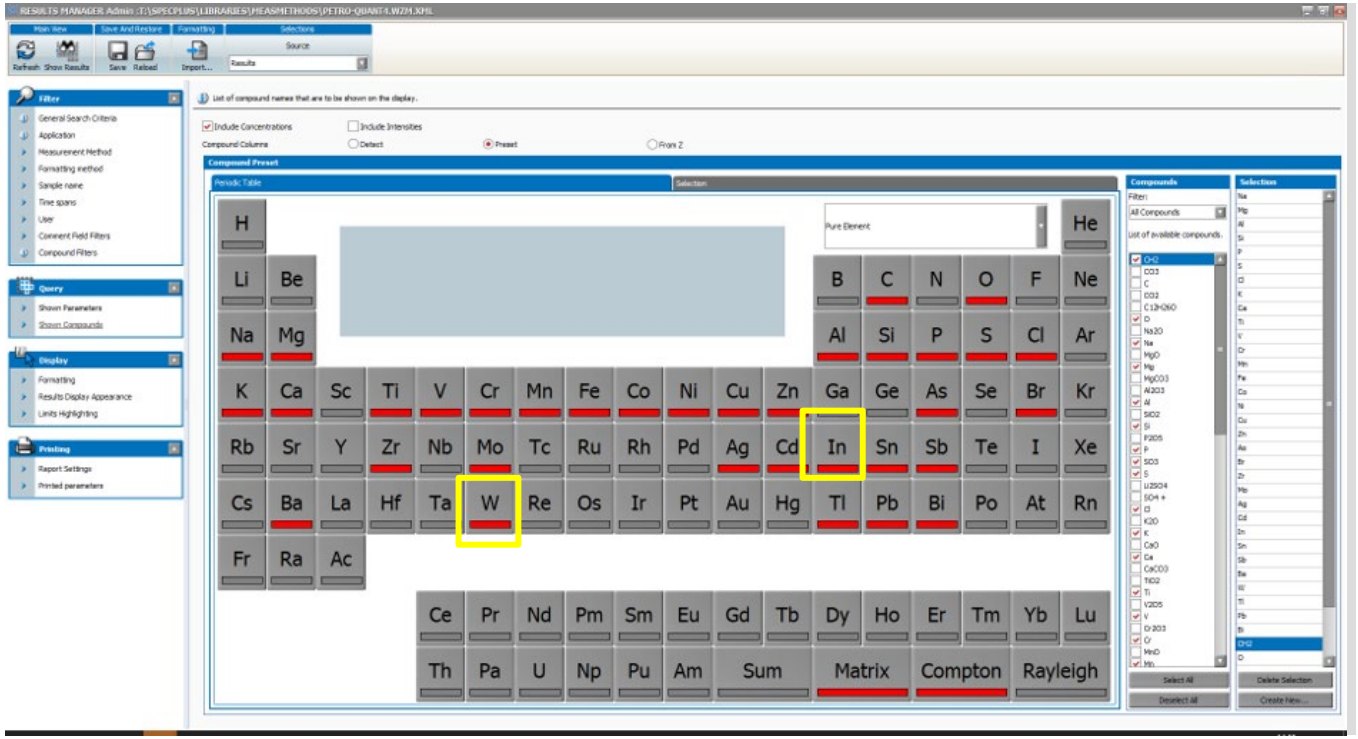
S8 TIGER News
XRF - Solutions for Industry and Research

Ready-To-Analyze Solutions for optimal Performance

- Factory setup
- Quick start into routine
- Ease-of-Use
- Best results
- Bruker expertise built in

PETRO-QUANT
Unique Solutions for Petrochemicals

- Universal petrochemical calibration up to 34 elements in hydrocarbon-based matrices – straight out of the box
  NEW: 2 additional elements: W and In as additives and contaminants
- Methods for best detection w/o DuraBeryllium™ Tube shield and w/ Tube shield for highest instrument uptime



Ready – To – Analyze Solutions for all petrochemical applications:

- in refineries, lubricant manufacturing, oil blending, engine development
- In plastics and polymer production

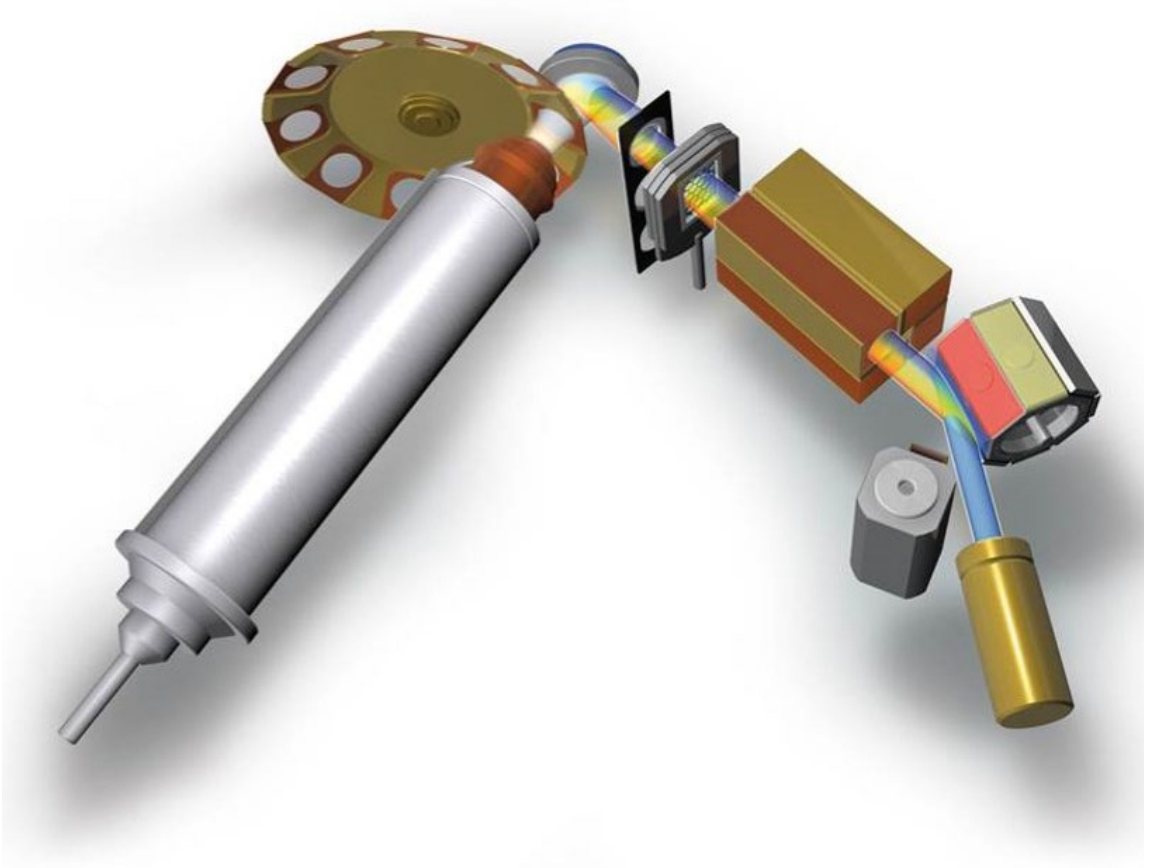
PETRO-QUANT
Unique Solutions for Petrochemicals

Universal Calibration for:

- Matrix: 95% or more hydrocarbons
- Elements: natural contaminants and technical additives
- Optimized sample prep for liquids and polymers
- Concentration ranges:
  S, Cl: LLD to 5% (heavy fuels and metal working fluids)
  Mg, P, S, Ca and Zn: up to several thousand PPM (additives)
  Ni, V and wear metals: max several hundred PPM (traces)

Performance

- LLD´s: a few ppm's, typically less than 1 PPM
- accuracy: a few ppm
- precision: a few ppm



PETRO-QUANT
Ultimate Analytical Performance

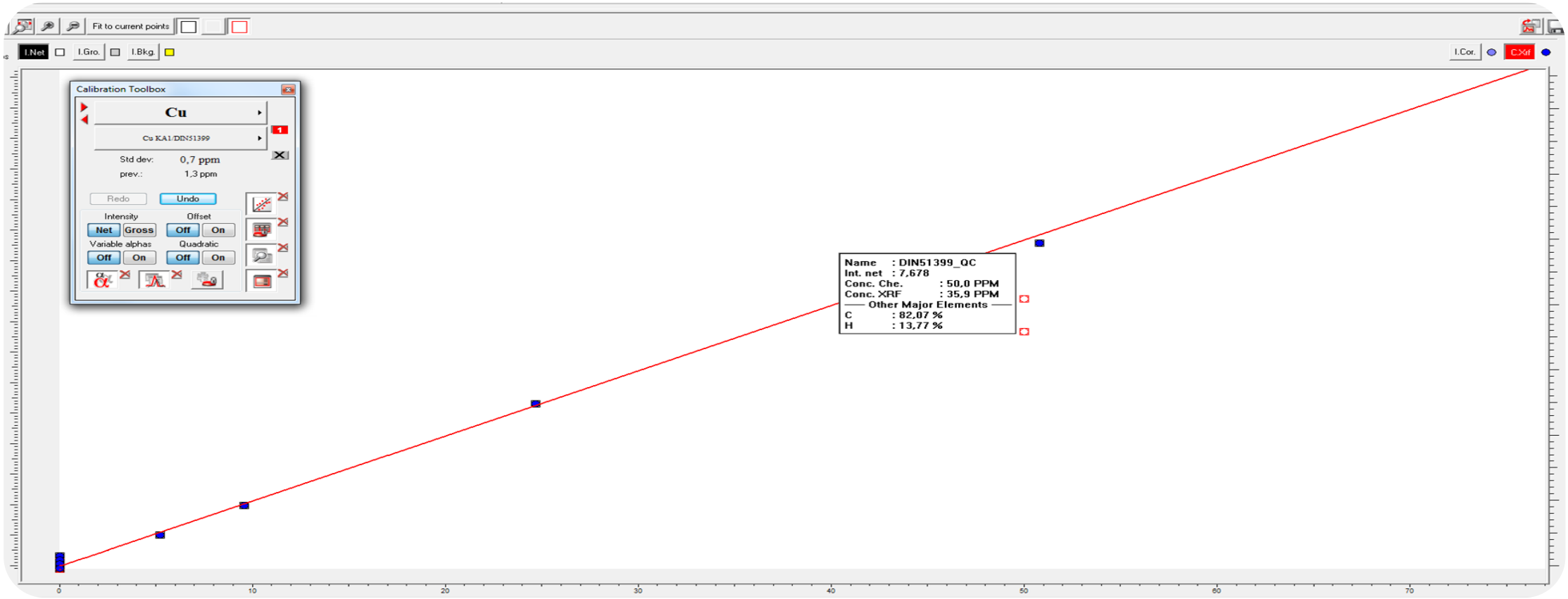
Universal Calibration for petrochemicals

based on SPECTRA*plus*:

- Variable alpha (Fundamental Parameter) model for wide concentration ranges
- Automatic selection of best lines for high concentrations (S, Cl) and severe line overlaps (As, Tl, Pb, Bi)
- Aut-O-matic: Quantification of light matrix

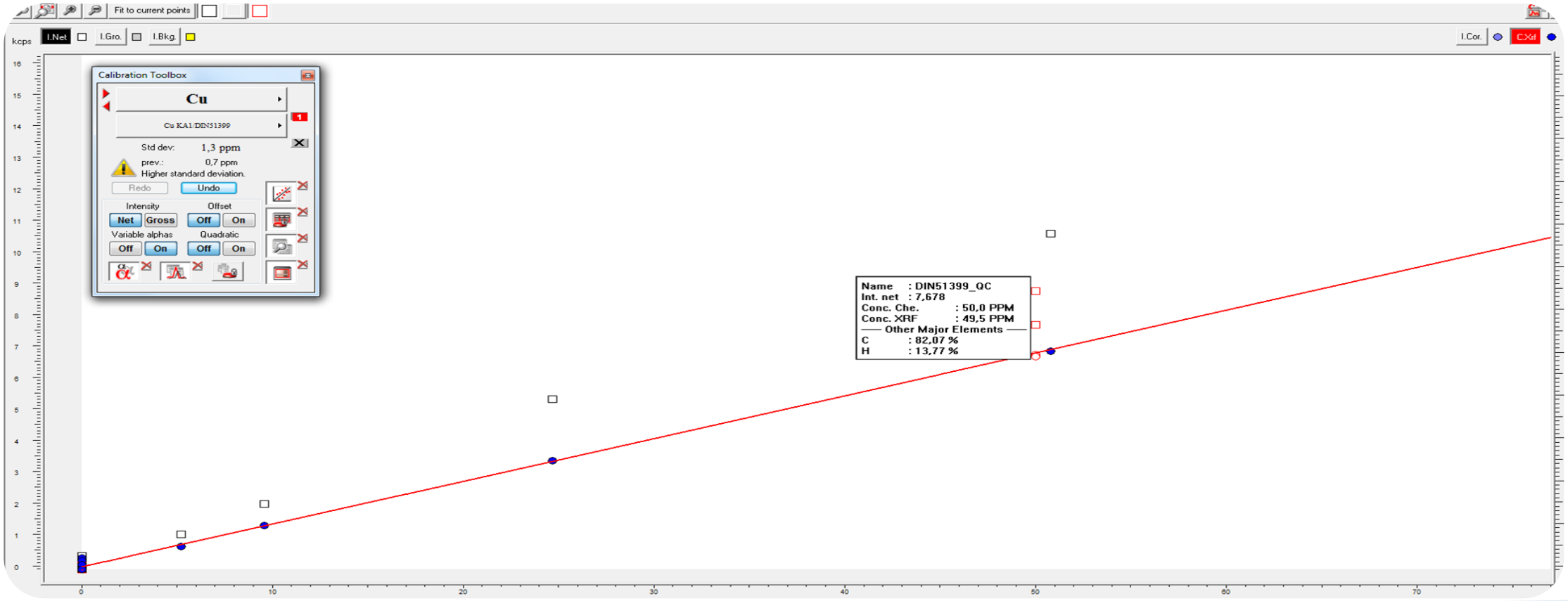
Matrix Effects for Wear Metals in Oils
Variation for S (up to 2.5 %) and O (up to 20%)

- Copper at 50 ppm evaluated as 35 ppm due to matrix effects not being compensated correctly – used oils contains considerable mounts of O, no longer comparable to pure CH_2 base oils



Matrix Effects for Wear Metals in Oils
Variation for S (up to 2.5 %) and O (up to 20%)

- Copper at 50 ppm evaluated as 49.5 ppm due to variable alpha matrix correction and oxygen evaluation by PETRO-QUANT Aut-O-Matic method



PETRO-QUANT
Ultimate Analytical Performance

Aut-O-matic:

Quantification of light element matrix

- Determining a compound using Compton Ratio:
- Oxygen cannot be measured directly (absorption of its intensity by the cup foil)
- Determination of additional matrix compounds using Compton optimization

- In hydrocarbons for example:
- The oil matrix (CH_2) is determined by the balance to 100%
- The oxygen content is determined by optimization of the Compton intensity

PETRO-QUANT
Ultimate Analytical Performance

Universal Calibration for petrochemicals

based on SPECTRA*plus*:

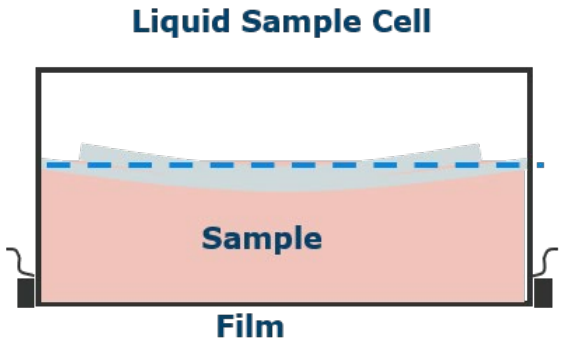
- Variable alpha (Fundamental Parameter) model for wide concentration ranges
- Automatic selection of best lines for high concentrations (S, Cl) and severe line overlaps (As, Tl, Pb, Bi)
- Aut-O-matic: Quantification of light matrix
- Geometric correction of wedge effect
- Meniscus correction

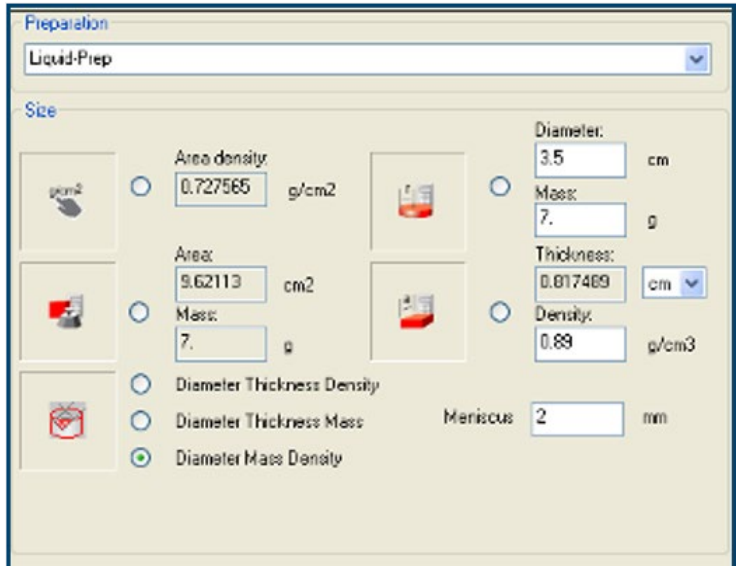
PETRO-QUANT
Ultimate Analytical Performance

Geometric Correction of Wedge Effect and Meniscus Correction

- Liquid samples often exhibit the meniscus effect, where the top surface of the liquid is concave instead of flat
- This will introduce errors in the calculation of the composition (wrong sample height)

- Meniscus Effect Correction for liquid samples:
- Insert size of the meniscus effect in the ApplicationWizard





PETRO-QUANT with the S8 TIGER 4 kW Analysis of Additives in Fresh Oils

- Control of additive element concentrations in fresh lubricating oils and related materials, such as grease:
  - Handle different densities as well as matrix effects from very light oil to grease
- Use Aut-O-Matic Matrix correction to extend PETRO-QUANT from fresh engine oils into aged oils from various oxidation states in dependence of usage

PETRO-QUANT
Fresh Lubricating Oils based on CH2 Blank Oil

PETRO-QUANT
Validation with proficiency testing

- Three samples are tested
  - Base oil
  - Low sulfur
  - High sulfur, additives

- Excellent agreement within confidence interval
- Best detection of traces

Round Robin Test
Fresh Lubricating Oils

	RR01		RR02		RR03	
	CERT	S8T(II)	CERT	S8T(II)	CERT	S8T(II)
Mg (ppm)	< 20	0	< 20	0	< 20	2
Si (ppm)	< 2	1	< 2	6	30	0
P (ppm)	<2	1	32	34	485	528
S (ppm)	<2	0	84	70	1688	1455
Cl (ppm)	< 2	0	< 2	0	30	28
Ca (ppm)	< 2	0	< 2	1	1113	1078
Zn (ppm)	< 2	0,3	< 2	0,4	556	561,5
Mo (ppm)	< 2	0	< 2	0	475	476,8

PETRO-QUANT
ASTM D6443: Lubricating Oils

	Mg	P	S	Cl	Ca	Cu	Zn
Cal. Range [ppm]	2000	1500	7500	1500	5000	500	1500
Detection Limit [ppm, 3s, 100s]	1.7	0.7	6.6	1.9	1	0.5	0.3
Repeatability [21 times]							
Mean value [ppm]	740	500	2780	510	1960	199	500
Abs. Std. Dev. [ppm]	10	4	15	2	3	0,7	4,7
Precision [%]	1.42	0.86	0.54	0.42	0.18	0.35	0.95

Analysis of Additives in Lubricants:

- Turn-key solution, norm compliant
- Ultimate high precision allows accurate blending
- Cost savings: expensive additives saved

PETRO-QUANT with the S8 TIGER 4 kW
Let's Make a Method for Racing…

- Control of engine oils for wear metals in motor development and for racing
- Remove elements from method to customize the application for exact requirement for speed and accuracy
- Lowest possible LLD with quick measurements:
  - lowest ppm level
  - short analysis time (≤ 10 min)
  - highest precision (≤ 1 ppm), esp. for Mg, Al, Si (≤ 2 ppm)
  - analyzes also particles (early warnings for engine breakdown)
  - Use Aut-O-Matic Matrix correction to correct for oxidation and therefore higher O concentration

PETRO-QUANT
Wear Metal Debris – Reference 10 ppm

Sample	Mg [ppm]	Al [ppm]	Si [ppm]	P [ppm]	Ca [ppm]	Ti [ppm]	V [ppm]	Cr [ppm]	Mn [ppm]
1	12.5	8.9	7.6	8.8	12.1	9.2	10.3	10.7	10.6
2	11.2	6.7	8.4	8.9	10.1	10.6	10.4	10.9	10.3
3	10.5	8.0	10.0	9.1	10.7	10.0	11.8	10.1	10.0
4	10.1	5.8	5.8	10.1	9.6	10.6	10.2	11.0	10.4
5	12.5	8.0	11.3	8.7	9.6	11.1	9.9	10.5	9.9
6	8.9	7.5	9.0	9.2	10.4	9.5	10.1	9.0	10.2
7	11.8	9.9	10.6	9.4	11.9	10.7	10.1	10.0	11.1
8	7.3	9.0	11.0	8.7	11.2	10.4	10.6	10.6	10.1
9	9.7	7.2	8.1	10.1	12.5	10.8	10.3	10.5	10.5
10	10.2	7.3	8.5	10.8	10.4	10.8	10.3	10.0	10.2
11	10.6	8.5	5.9	8.9	11.1	9.8	10.3	10.0	9.9
12	8.4	8.3	6.5	9.3	12.5	10.4	11.2	10.3	10.1
Mean	**10.3**	**7.9**	**8.6**	**9.3**	**11.0**	**10.3**	**10.5**	**10.3**	**10.3**
Std. Dev.	**1.6**	**1.1**	**1.9**	**0.7**	**1.0**	**0.6**	**0.5**	**0.5**	**0.3**
Max	**12.5**	**9.9**	**11.3**	**10.8**	**12.5**	**11.1**	**11.8**	**11.0**	**11.1**
Min	**7.3**	**5.8**	**5.8**	**8.7**	**9.6**	**9.2**	**9.9**	**9.0**	**9.9**
Range	**5.2**	**4.1**	**5.5**	**2.1**	**2.9**	**1.9**	**1.9**	**2.0**	**1.2**

- Modern combustion engines are containing Mg-Al-Si alloys
  - Especially early warnings of debris from light elements are difficult to be detected by EDXRF
  - Metal parts are not detected by ICP-OES (separation in nebulizer) or in the Rotrode OES (not collected on electrode)
  - But detected with WDXRF
- Excellent precision enables early recognition of changes in the composition

PETRO-QUANT
Wear Metal Debris – Reference 10 ppm

Sample	Fe [ppm]	Ni [ppm]	Cu [ppm]	Zn [ppm]	Mo [ppm]	Sn [ppm]	Pb [ppm]
1	10.5	11.0	10.2	9.9	9.8	9.8	9.1
2	9.7	9.9	10.0	9.9	9.3	11.8	9.8
3	9.4	10.2	9.9	9.8	9.6	10.5	9.4
4	11.0	10.1	10.1	9.9	9.3	8.2	9.7
5	9.3	11.0	10.3	9.6	9.7	6.6	10.1
6	10.2	10.2	10.1	9.7	8.3	9.8	9.8
7	9.6	10.5	10.0	9.8	8.9	10.5	10.1
8	10.2	10.2	10.2	10.1	8.5	14.0	9.9
9	9.6	9.9	10.5	10.1	9.9	9.4	9.6
10	9.7	10,2	10.1	10.4	9.1	11.0	9.5
11	9.1	10.5	10.3	9.9	10.0	9.4	9.7
12	10.4	10.3	10.4	9.9	9.8	10.0	10.0
Mean	**9.9**	**10.3**	**10.2**	**9.9**	**9.4**	**10,1**	**9.7**
Std Dev	**0.6**	**0.4**	**0.2**	**0.2**	**0.6**	**1.8**	**0.3**
Max	**11.0**	**11.0**	**10.5**	**10.4**	**10.0**	**14.0**	**10.1**
Min	**9.1**	**9.9**	**9.9**	**9.6**	**8.3**	**6.6**	**9.1**
Range	**1.9**	**1.1**	**0.6**	**0.8**	**1.7**	**7.4**	**1.0**

- Heavy elements mainly derives in modern engine from plasma coatings on cylinder walls, and bearings
  - Knowing the alloy composition failing components are quickly identified when all elements are increasing (same ratio than alloy composition)
  - Early warning for engine failures
  - Database of engine components are enabling proper fleet management (maintenance based on XRF analysis)

BRUKER's Strength - EDXRF
Complete Product Range for Lubricants

S2 POLAR:

- Dedicated polarized EDXRF for petrochemical applications
- ASTM D7751, D6481

S2 PUMA:

- Powerful all-round benchtop EDXRF, SMART-QUANT FP
- ASTM D7751, D6481
- With good performance for wear metal

S2 POLAR

S2 PUMA

BRUKER's Strength - WDXRF
Complete Product Range for Lubricants

S6 JAGUAR:

- Compact benchtop WDXRF for petrochemical labs
- ASTM D6443, D2622, D5059
- ISO 51399

S8 TIGER:

- For high demanding central labs

S6 JAGUAR

S8 TIGER

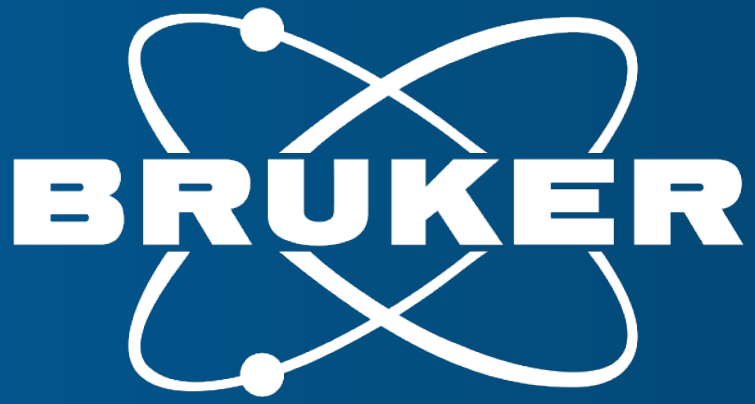
Any Questions?

Learn more about analysis of polymers by XRF and how to achieve significant cost reduction in polymer production

In our 9.6.2021 webinar – Sign Up Now!

Thank you!

Kai Behrens Frank Portala Adrian Fiege



Innovation with Integrity