Q5800 – A COMPREHENSIVE SOLUTION FOR EXPEDITIONARY "ON THE MOVE" OIL ANALYSIS

Dan Walsh Director of Product Management | Spectro Scientific

Patrick Henning, PhD. Chief Technology Officer | Spectro Scientific

Thomas Barraclough Product Engineering Manager | Spectro Scientific

Synopsis

Traditionally, oil analysis has been performed in dedicated laboratories equipped with instrumentation tailored specifically to report quantifiable data on both oil and machine condition. The goal of condition-based maintenance through oil analysis is to be able to extend the useful life of the oil, limit machine downtime, extend the life of the machine and avoid catastrophic failures.
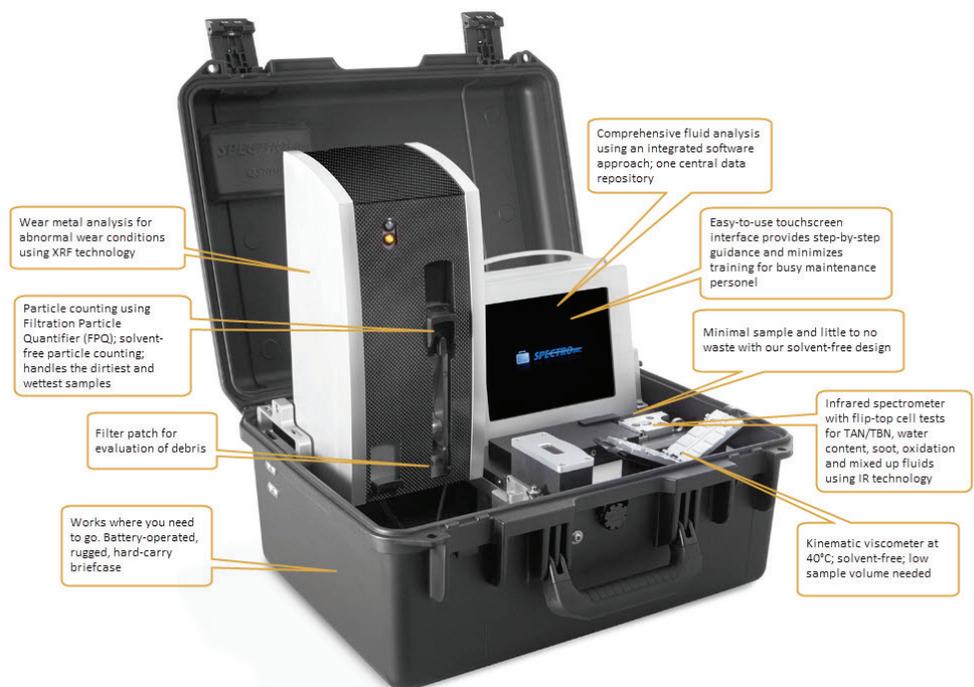
This paper describes how the Q5800 serves as a single portable solution providing cost effective, integrated lubrication analysis. As instrumentation size shrinks and becomes more portable, oil analysis devices are being put in the hands of the end user. It is proven that these new smaller devices do not sacrifice analytical performance. This brings the end user closer to the machine and its problems. The Q5800 takes this one step further and combines an array of portable-sized instrumentation into a single unique device users can carry. It combines all of the instrumentation necessary to answer critical oil analysis questions about lubricant condition and machine condition. The device operates entirely solvent free, enabling operation anywhere.

Introduction – Understanding Q5800 Technologies

Technologies

The Q5800 is comprised of the following three major components:

- Filtration Particle Quantifier (FPQ) Tower — provides abnormal wear metal analysis using XRF technology and particle counting

- Kinematic Viscometer at 40°C — provides solvent-free measurements of a lubricant's kinematic viscosity

- Infrared Spectrometer with Flip-Top Cell — provides tests for TAN/TBN, water content, soot, oxidation and mixed up fluids using infrared technology

Wear metal analysis for abnormal wear conditions using XRF technology

Particle counting using Filtration Particle Quantifier (FPQ); solvent-free particle counting; handles the dirtiest and wettest samples

Filter patch for evaluation of debris

Works where you need to go. Battery-operated, rugged, hard-carry briefcase

Comprehensive fluid analysis using an integrated software approach; one central data repository

Easy-to-use touchscreen interface provides step-by-step guidance and minimizes training for busy maintenance personel

Minimal sample and little to no waste with our solvent-free design

Infrared spectrometer with flip-top cell tests for TAN/TBN, water content, soot, oxidation and mixed up fluids using IR technology

Kinematic viscometer at 40°C; solvent-free; low sample volume needed

Figure 1: Q5800 Components and Functions

Principle of Operation

This section provides the basic operating principles of the Q5800 device by component.

Filtration Particle Quantifier (FPQ) Tower

Machine condition has traditionally been measured using spectrometric techniques such as RDE or ICP spectroscopy. Wear debris analysis using Ferrography is performed to establish the root cause of a wear problem. This is done using an expert with high powered microscopes and wear particle morphology techniques to assess different wear types and mechanisms in the lubrication system. More recently, direct imaging particle counting using LaserNet Fines® has proven to be a very effective screening technique for Ferrography. Contamination control in very clean systems such as hydraulics continues to be undertaken by traditional, light blocking, optical particle counting techniques.

For a portable device such as the Q5800, none of these methods prove suitable. They are either too big, too power hungry, require too much solvent or are simply too sample preparation intensive.

The Q5800 uses a new combination of particle filtration and XRF to assess machine condition by tying the particle count and elemental wear metal distribution in the sample together. It is able to do this for a wide range of used oil applications that vary in particle concentration without the need for solvents and using only 3ml of oil.

The Filtration Particle Quantifier FPQ is a patent pending device able to obtain an accurate particle count for a given filter size. It does this by measuring the pressure rise across the filter as the pores become blocked with particles. Unlike traditional "pore blockage" technology, it has a particle measuring range from 2,500 to 1,500,000 p/ml. It is able to achieve this range by using its unique, dual dynamic patented filter design that eliminates saturation of the filter and allows for further quantification of particles in the caking region. The device is impervious to soot from diesel engines and water contamination which in optical particle counting can often skew results and cause confusion.

The device ensures that the particles deposited on the filter reach a maximum level for a given shut off pressure. This pressure is set below the caking region of the filter where "particle swapping" occurs. This ensures that a correct particle deposition and oil volume can be obtained for subsequent XRF analyses. Once the particle count is complete, the filter slide is transferred to the XRF for

analysis where the elemental breakdown of the sample is quantified. This is where the root cause of the failure can be identified and is akin to Ferrography analysis.

Figure 2 shows the tower which encompasses the FPQ and XRF device in the overall oil monitor system. The figure also shows the filter being inserted into the XRF. This relatively quick process can screen out samples with high particle counts and perform a complete 13 element XRF analysis on the resultant sample filter.

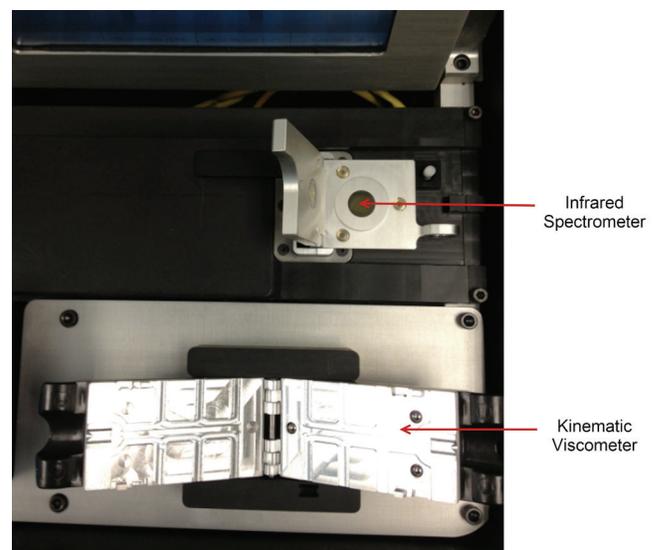**Figure 2:** FPQ and XRF Tower Assembly

Figure 3: Close-up of IR Spectrometer and Kinematic Viscometer in the Q5800

Kinematic Viscometer at 40°C Infrared Spectrometer with Flip-Top Cell

Lubricant condition is an important aspect of oil analysis that needs to be constantly monitored. A change in an oil type's viscosity can comprise film thickness leading to excessive wear and subsequent failures. The viscosity of an oil type can become compromised by fluid contamination or oil degradation. The Q5800 uses the technology from its successful patented wedged IR Spectrometer (FluidScan®) and the Q3000 kinematic viscometer to glean critical oil condition parameters.

Like their portable counterparts, both these instruments operate seamlessly without the need for any solvents in the Q5800 enclosure. The results can easily be compared or correlated to a typical lab, reporting viscosity in cSt and IR measurements in ppm, abs/mm2 or abs/cm.

	Reporting Units	LOD ~	Range
Soot	%wt	0.01%	0-5
Water	ppm	100	100- 50,000
TBN	mgKOH/g	0	0-50
TAN	mgKOH/g	0.25	0-6
Oxidation	abs/mm2	0.5	n/a
Nitration	abs/mm2	0.5	n/a
Sulfation	abs/mm2	0.5	n/a
AW Additive	abs/mm2	3.0	0-100
Glycol	%vol	0.2	0-10

Figure 4: IR Properties

Case Study – Real World Sample Testing

LaserNet Fines"R) direct imaging and spectroscopy are well established techniques to quantify particle count and elemental concentration respectively. It is well known that RDE and ICP spectrometers lack good sensitivity to detect large particles and they are used as trending tools for fine particles based on a dissolved elemental calibration. An accepted methodology to quantify large particles is to acid digest the entire sample, dissolving the particles into a liquid which can be quantified using a standard ICP calibration. However, corrosive chemicals, time, cost and effort make acid digestion impractical.

Example #1: Marine Engine FPQ / XRF Data Set

The following data set from a series of marine diesel vessels was used to evaluate the FPQ and XRF technology. Samples were analyzed on the FPQ device and XRF and were shown to correlate to LaserNet Fines® and acid digestion using the ICP. A model using an assumed wear particle size aspect ratio and particle mass was used to further correlate the aggregate elemental concentration on the FPQ filter using the LaserNet Fines® and XRF data. Figure 5 and Figure 6 show how the FPQ and XRF correlate to the LaserNet Fines® direct imaging particle counter.
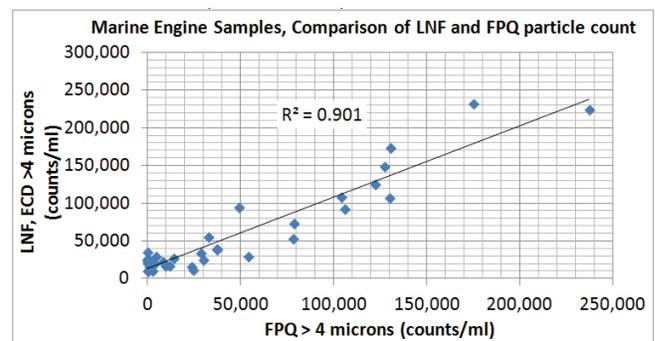

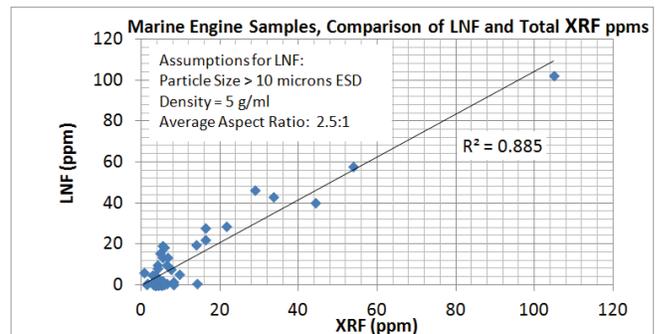**Figure 5:** LaserNet Fines® vs. FPQ (counts/ml >4um)


Figure 6: LaserNet Fines® vs. XRF – Total ppms

XRF vs. Acid Digestions

The data in Table 1 below shows a selection of the marine samples that were analyzed on the ICP before and after acid digestion. This method is commonly known as differential acid digestion. As expected, the delta ppm between the two ICP readings shows that the concentration of the large wear particle portion in the sample (~ >5um) is relatively small compared to the total fine material present in the sample. The large particle portion correlates very well (within 3ppm) of the filtered XRF results.

Sample	Before Acid Digestion - ICP (ppm)						After Acid Digestion - ICP (ppm)					
	A	B	C	D	E	F	A	B	C	D	E	F
Ag	0	0	0	0	0	0	0	0	0	0	0	0
Al	0	0	0	10	10	21	0	0	0	0	13	28
Cr	6	0	0	0	6	7	6	0	0	0	6	8
Cu	0	0	0	0	11	11	0	0	0	0	10	10
Fe	10	7	0	0	33	67	11	10	0	0	35	86
Mo	0	0	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0	0	0	0	0	0	0	0	0
Pb	0	0	0	0	0	0	0	0	0	0	0	0
Sn	0	0	0	0	0	0	0	0	0	0	0	0
Ti	0	0	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0
Total ppm	16	7	0	10	60	106	17	10	0	0	64	132

Table 1: Differential Acid Digestion Sample Result (Sample E= 10-1151, Sample F= 10-1149)

Figure 7 shows how the differential ICP results (large particles) for samples E and F compare to the XRF data for the same samples. Note that the XRF data is not shown in Table 1 above. The large particle portion correlates very well (within 3ppm) of the filtered XRF results (Figure 7).
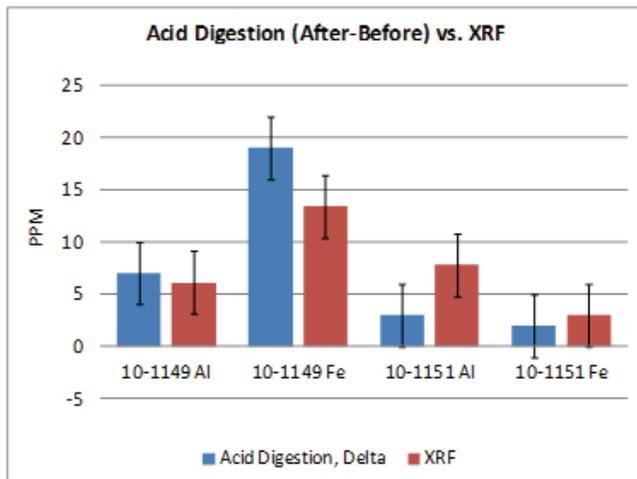
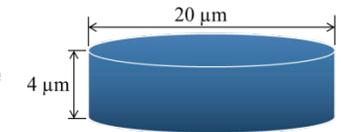**Figure 7:** Acid Digestion (After – Before) vs XRF
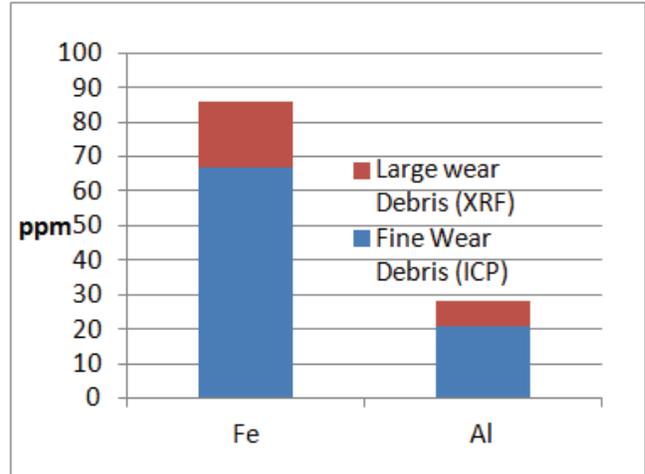
Figure 8: Sample F – Fine vs Large Particles

Figure 8 shows the difference in ppms between the ICP and XRF readings for Fe and Al in sample F. This is an expected result based on how large and small particles behave in a closed loop lubricating system. Large particles get lost and filtered out far more easily compared to fine debris which never gets lost and will continue to grow in concentration.

Acid digestion is not normally performed for condition monitoring oil analysis for expediency, though large particles are indicative of abnormal equipment conditions.

Based on the density of iron, it would take 100 particles of the illustrated dimensions in 1ml of oil to raise the elemental concentration by just 1ppm. For lighter metals like Aluminum, it would take approximately three times this amount of particles. This explains why the differential elemental ICP and XRF readings are relatively low when compared to the fine and dissolved particle readings using routine spectroscopy. In this example, the Fe and Al is most likely cylinder/piston wear. This is a common failure mode in this application and shows how the XRF is able to identify root causes of problems.

Example #2: Wear Progression to Failure

Example #2: Wear Progression to Failure

When a machine enters an abnormal wear mode there is always an increase in the size and rate of production of severe wear particles. They are identified as an increase from a known equilibrium level in the system. As abnormal wear progresses, the size and the rate of

production of these particles increases until eventually the system fails. The XRF and FPQ have been shown to excel in tandem at interpreting machine wear in this region.

Note that fine wear particles detected by RDE spectroscopy and ICP continue to rise in the lube system and they are unaffected by filtration or other system loss mechanisms. Take care when changing the oil and subsequently interpreting fine and dissolved wear metal data vs. XRF data. Limits based on rate of change apply in this case, but for larger particles measured by FPQ and XRF, a static limit applies after the system reaches equilibrium.
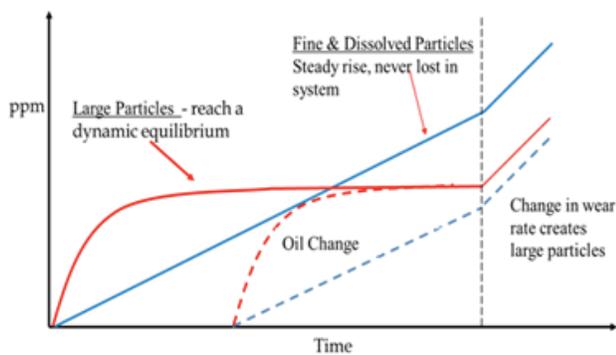

Figure 9: Behavior of Large vs. Fine Particles

Unlike existing optical particle counter and pore blockage technologies, the FPQ can handle a wide range of applications with relatively high wear rates (up to 1.5 million p/ml). The following data shows FPQ and XRF data for a wide range of components that are typically found in heavy duty industrial vehicle equipment: engines, transmissions, final drives, and front differentials. The data shows pairs of components with corresponding high and low wear rates.

Sample	Particles >4um (/ml) LaserNet Fines	FPQ data	Application	ITS Q 5800 XRF (ppm) Al	Cu	Fe	Si
E1 High wear	180209	141795	Engine	2.0	0.0	0.8	1.4
E2 Low Wear	26802	44188	Engine	0.5	0.6	0.6	0.7
T1 High Wear	46618	50390	Transmission	0.4	2.2	2.2	1.7
T2 Low Wear	5346	9664	Transmission	0.0	0.0	0.2	0.3
F1 High wear	213674	226222	Final Drive	4.3	0.0	8.4	7.0
F2 Low Wear	17185	26948	Final Drive	0.1	0.0	2.0	0.5
D1 High Wear	88193	62259	Front Diff	1.2	0.0	4.2	1.9
D2 Low Wear	37613	34773	Front Diff	0.9	0.7	2.9	1.2
E3 High Water	1025329	31686	Engine	0.5	0.0	1.0	0.4

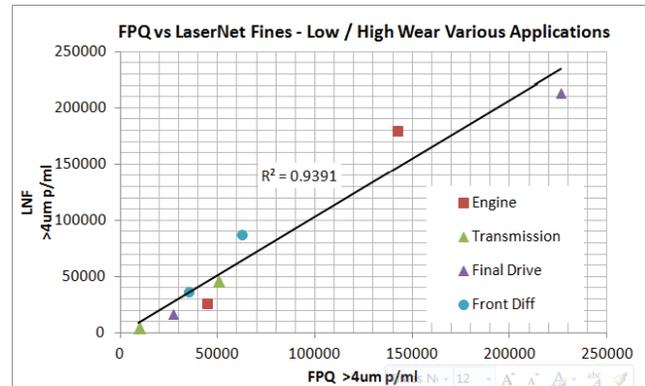**Table 2:** Normal and Abnormal FPQ & XRF data for various applications

Figure 10: FPQ vs LaserNet Fines, normal and abnormal wear in different applications

As expected the particle count on the FPQ correlates very well with direct imaging particle counting. In addition, the elemental XRF readings differentiate between low wearing systems and more critical, highly wearing systems. Using this data, it is possible to make a recommendation on the root cause of the increased wear rates based on a material map of the lube system.

This data set also demonstrates a unique advantage that the FPQ has when analyzing emulsions and other sample types that contain "phantom" particles that are included in the overall particle count. Water and other liquids pass through the polycarbonate filter pores and the results are unaffected.

Sample E3 (shown in Table 2 in red font) contains a significant amount of free water ingestion that produced a highly elevated particle count reading on the LaserNet Fines®. The real particle count in this sample was only ~ 31k p/ml and the elemental level was low.

Conclusion

The Q5800 is a revolutionary tool that takes oil analysis to the machine using a rugged, portable device equipped with a suite of miniaturized state-of-the-art instrumentation. The device is able to accurately quantify both lubricant and machine condition parameters for a variety of assets. Lubricant condition is derived using an established portable IR technique along with a solvent- free kinematic viscosity measurement. Machine condition using filtration particle counting and XRF is where the device excels compared to existing machine condition portable technologies.

The FPQ, with its patent pending dual dynamic filtration system has been shown to handle a wide range of lubricant applications with varying wear levels. The particle count using the FPQ filter

also correlates with existing direct imaging particle counting. The subsequent elemental concentration from the FPQ filter using XRF analysis correlates well with differential acid digestion. This combined

particle count and elemental concentration can be used to identify changing wear rates and isolate potential root causes of problems in lube systems.

References

[1] Daniel P. Anderson and Richard D. Driver. "Equilibrium particle concentration in engine oil" Wear, Volume 56, Issue 2, October 1979, Pages 415-419

[2] Reda, A.A., Bowen, E.R., and Westcott, V.C. "Characteristics of Particles Generated at the interface Between Sliding Steel Surfaces" Wear, Volume 34 (1975) Pages 261-273

[3] Anderson, D.P., "Wear Particle Atlas (Revised)" prepared for the Naval Air Engineering Center, Lakehurst, NJ 08733, 28 June 1982, Report NAEC-92-163, Approved for Public Release; Distribution Unlimited – Pages 125-134

[4] Mark Smith, Analysts, Inc., "Oil Analysis vs. Microscopic Debris Analysis – When and Why to Choose," Pages 1-9