

ICP - Mass Spectrometry

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Benefits of NexION 300/350 ICP-MS Technology for the Analysis of Power Plant Flue Gas Desulfurization Wastewaters

Introduction

One of the most widely used technologies for removing pollutants, such as sulfur dioxide, from flue gas emissions produced by coal-fired power plants, is the limestone-forced oxidation scrubbing system. More commonly known as flue gas desulfurization (FGD), this process employs gas scrubbers to spray limestone

slurry over the flue gas to convert gaseous sulfur dioxide to calcium sulfate.¹ Unfortunately, many of the contaminants from the coal, limestone and make-up water are concentrated in the circulating water of the scrubbing system. So in order to maintain appropriate plant operating conditions, a constant purge stream of water containing these contaminants has to be discharged from the scrubbers while fresh limestone slurry is fed in. This purge stream is extremely acidic and saturated with high concentrations of gypsum, heavy metals, alkali earth metals, chlorides and dissolved organic compounds. A schematic of a typical FGD process is shown in Figure 1.

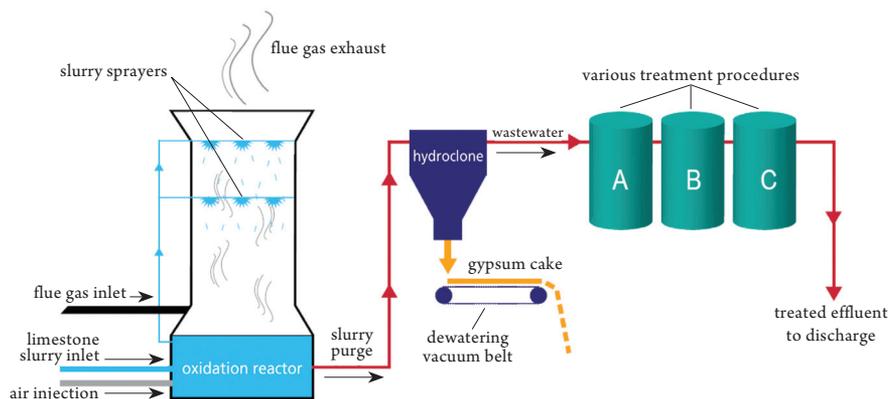


Figure 1. The flue gas desulfurization (FGD) process.

State and Federal laws regulate the concentration of pollutants in FGD wastewater prior to discharge into the waterways. In some cases, the wastewater may be suitable for discharge after minor treatment such as filtering out suspended solids and/or adjusting the pH. However, in many cases, the wastewater requires treatment for the reduction of the major pollutants. The scrubber purge stream is most often treated in a dedicated wastewater facility because the existing treatment system may not have adequate capacity; or the design might be unsuitable for receiving high chloride streams. In some cases, it just might not be appropriate for the very strict wastewater discharge limits likely to be enforced by the U.S. Environmental Protection Agency (EPA) for FGD wastewater.

The composition of flue gas desulfurization wastewaters (FGDW) can vary significantly from plant to plant, depending on the capacity of the boiler, chloride concentration of the scrubber, rate of fly ash removal, efficiency of the gypsum dewatering system, type of FGD process used, and the composition of coal, limestone and make-up water. The U.S. EPA wrote wastewater effluent limit guidelines for discharge permits granted to coal-fired power plants back in 1982.² The rule, known as 40 CFR Part 423, has not kept pace with changes in the industry over the past several decades, even though industry air pollution controls are much more efficient today. For that reason, the U.S. EPA has recently taken on the task of revising the rule with new proposed revisions expected in November 2012 and the final rule expected by April 2014.

New Draft U.S. EPA ICP-MS Standard Operating Procedure

To support the modification to this rule, the U.S. EPA is developing a new ICP-MS method specifically for FGD wastewaters.³ Unfortunately, this type of sample poses significant problems for the technique, because not only does it contain extremely high concentrations of dissolved solids, which can be very challenging, but also because no two FGDW samples are exactly the same. This means the matrix components, such as chlorides, sulfates and organic material, are continually changing, which makes the real-world analysis of FGDW samples very challenging.⁴

The new draft method, entitled *“Standard Operating Procedure: Inductively Coupled Plasma-Mass Spectrometry for Trace Element Analysis in Flue Gas Desulfurization Wastewaters”* proposed by the U.S. EPA Office of Water Engineering & Analysis Division, describes a procedure to measure elements in FGD wastewaters by ICP-MS using

collision/reaction cell technology. This procedure is based on Method 200.8 – the analysis of ground waters, surface waters, drinking waters, and wastewaters by ICP-MS;⁵ and Method 1638 – the determination of trace metals in ambient waters by ICP-MS.⁶ Both these methods were designed to support water quality programs under the Clean Water Act, which requires the U.S. EPA to publish water quality criteria that reflects the latest scientific knowledge concerning the effect of pollutants on ecological and human health.

This procedure is applicable to the determination of thirteen elements (Al, As, Cd, Cr, Cu, Pb, Mn, Ni, Se, Ag, Tl, V and Zn) in acid-digested FGD wastewater, utilizing a collision and/or reaction cell to remove molecular interferences and internal standardization to compensate for suppression and enhancement effects caused by sample matrices.

Optimized Analytical Method

The objective of this particular study was to investigate the capability of the NexION® 300 ICP-MS technology (PerkinElmer, Shelton, CT) using the new draft U.S. EPA procedure for FGDW. The NexION has been described in the open literature,⁷ but it is worth outlining the benefits of the technology for carrying out this extremely difficult analysis.

The instrument offers the simplicity and convenience of a traditional collision cell with Kinetic Energy Discrimination (KED) and the recognized superior detection limits of a true reaction cell. With this patented Universal Cell Technology™ (UCT), analysts can now choose the most appropriate collision/reaction cell conditions for each analyte in FGDW samples, without any restrictions to the type of gases that can be used. The three modes of interference removal available in the NexION 300 are:

- **Standard mode:** The cell is actively vented. This enables the instrument to be run in true Standard mode, with the cell conditions optimized for maximum ion transmission. For FGDW samples, this mode is ideal for heavy metals like Pb and Tl, where there are very few polyatomic spectral interferences to be concerned about.
- **Collision mode:** In this mode, the instrument offers conventional collision cell capability with KED. By using a non-reactive gas, such as helium (He), the Collision mode with KED removes many of the simple solvent- and argon-based polyatomic spectral interferences. This makes it ideal for elements such as Co, Ni, Cu and Zn, which are prone to the larger cross-sectional polyatomic interferences.

- **Reaction mode:** Recognized as the technique that offers the ultimate detection capability, the instrument's true Reaction mode, also known as DRC (Dynamic Reaction Cell™) technology, removes the majority of interferences with little or no loss of analyte sensitivity. DRC technology features a scanning quadrupole with a bandpass that removes by-product reactions created in the Universal Cell. Therefore any reaction gas can be used. And by optimizing the cell's quadrupole conditions, only the element of interest is allowed to pass through to the analyzing quadrupole. It is well recognized that ion-molecule reaction chemistry offers the very best performance for the reduction of polyatomic interference.⁸ This would be the mode of choice for the lowest possible detection limits for elements such as Cr, V and Mn, which are recognized as being the most difficult to determine in a complex FGDW matrix.

The NexION also features a unique Triple Cone Interface (TCI), which includes an additional hyper skimmer cone to tightly define and focus the ion beam entering the Quadrupole Ion Deflector (QID), with very little maintenance, even for FGDW samples, other than the sampler and skimmer cones. All three cones can be quickly and easily removed, cleaned or replaced, which is particularly relevant for the analysis of FGDWs that contain high levels of matrix components.

The highly focused ion beam then emerges from the TCI and enters a QID, which is designed around a proprietary, miniaturized quadrupole. This breakthrough filtering technology bends the ion beam 90 degrees, focusing those of a specified mass into the universal cell and discarding all neutral species into the turbo pump. The path through the QID is aligned with the tightly defined beam leaving the TCI, which ensures that ions and neutral species never impact or degrade component surfaces within the cell, virtually eliminating the need for cleaning. By removing the majority of particulates, neutrals and photons, this practical design significantly minimizes drift and delivers exceptional signal stability, even when running the most challenging FGDW sample matrices.

Method Sample Preparation

Sample preparation was carried out as follows: A ten-fold dilution of FGDW samples were followed by an open-vessel digestion in a block digester according to U.S. EPA Method 1638 – aqueous sample preparation – total recoverable metals – Section 12.2.1-12.2.7. The final acid concentration of samples, calibration standards, and blank was 2% HNO₃ + 0.5% HCl.

Instrument Parameters

A NexION 300D ICP-MS, coupled with an SC-DX FAST (ESI, Omaha, NE) automated sample delivery system, was used for the investigation. This intelligent delivery system has been described in the open literature,^{9,10} but is basically a rapid flow injection technique integrated into an autosampler, which significantly reduces the pre- and post-measurement times involved with delivering a new sample to and removing the previous sample from the ICP-MS. By optimizing these times, a significant improvement can be made in the sample throughput. As a result, the measurement time for 3 replicates was 1.5 minutes, and the total analysis time, sample to sample, was 2.5 minutes for the 22 isotopes monitored. The major ICP-MS instrument operating parameters are shown in Table 1.

Table 1. Instrument operating conditions.

Component/Parameter	Type/Value/Mode
Nebulizer	PFA ST
Spray Chamber	Peltier-cooled baffled quartz cyclonic
Triple Cone Interface Material	Nickel
Plasma Gas Flow	16.0 L/min
Auxiliary Gas Flow	1.2 L/min
Nebulizer Gas Flow	0.98 L/min
Sample Uptake Rate	270 µL/min
RF Power	1600 W
Analytes	Al, As, Cd, Cr, Cu, Pb, Mn, Ni, Se, Ag, Tl, V and Zn
Internal Standards	Sc, In, Ge (added on line)
Isotopes Monitored	22 (analytes and internal standards)
Modes of Operation	1. Standard 2. Collision/KED (He gas) 3. Reaction (NH ₃ gas)
Replicates per Sample	3
Measurement Time (3 replicates)	1 min 30 sec
Analysis Time (sample to sample)	2 min 30 sec

Proposed U.S. EPA FGDW Methodology

Before a suite of samples can be analyzed, a set of protocols, similar in design to other U.S. EPA ICP-MS analytical procedures such as Method 200.8, must be followed to ensure the instrument is working at its optimum performance.¹¹ A summary of these protocols is shown in Table 2. This analytical run sequence outlined should be performed on a daily basis in order to meet all quality control requirements. Note: The samples shown in the first section of the table (steps 1-19) must be run once per sequence, while the 10 samples and the final continuing calibration verification (CCV) and continuing calibration blank (CCB) samples must be repeated.

Table 2. A summary of the analytical run sequence of the FGDW standard operating procedure (SOP).

Analyzed once per sequence	1. Turn on instrument
	2. Warm up instrument
	3. Tune instrument
	4. Perform mass calibration
	5. Perform resolution check
	6. Validate tuning criteria
	7. Calibration blank
	8. Calibration standard 1
	9. Calibration standard 2
	10. Calibration standard 3
	11. More standards if required
	12. Initial calibration verification (ICV)
	13. Initial calibration blank (ICB)
	14. Reporting limit (RL) verification standard
	15. Synthetic FGD wastewater matrix
	16. Spiked synthetic FGD matrix
	17. Continuing calibration blank (CCB) (carryover check)
	18. Continuing calibration verification (CCV)
	19. Continuing calibration blank (CCB)
Must be repeated	20. 10 Samples, which must contain a laboratory control sample (LCS) plus one matrix spike (MS) and matrix spike duplicate (MSD)
	21. CCV
	22. CCB

It's also worth explaining some of the terminology in this procedure, as typical performance data will be presented later in the study.

- **Initial calibration verification (ICV):** Multielement standard of known concentrations prepared to verify instrument calibration. This solution must be an independent standard prepared near the mid-point of the calibration curve, and at a concentration other than that used for instrument calibration.
- **Continuing calibration verification (CCV):** A multi-element standard of known concentrations prepared to monitor and verify the instrument's daily continuing performance. This is monitored after every ten (10) samples and at the end of an analytical sequence.
- **Reporting limit (RL) verification standard:** The minimum concentration that can be reported with a specified degree of confidence. The RL can be no lower than the concentration of the lowest initial calibration standard.
- **Laboratory control sample (LCS):** A multielement standard of known concentrations that is carried through the entire sample preparation and analysis procedure. This solution is used to verify method performance in an ideal sample matrix.
- **Synthetic FGD wastewater matrix:** A prepared mixed solution of major constituents at typical concentrations found in FGDW.
- **Matrix spike (MS):** A laboratory fortified sample (LFS) to which known concentrations of the analyte elements of interest are added. This fortified sample is taken through all preparation and analytical steps of the procedure. The results are used to determine the effectiveness of the digestion procedure and any effects of the sample matrix on analyte-recovery efficiency.

This procedure has to be carried out on a daily basis. However, instrument detection limits (IDLs) must be carried out on a quarterly basis and method detection limits (MDLs) have to be carried out on an annual basis. It's important to emphasize that an initial IDL and MDL study must be performed on each instrument before samples can be analyzed. IDLs and MDLs are calculated in the following way:

- **Instrument detection limit (IDL):** Prepare ten (10) separate calibration blanks. For each analyte, analyze the 10 blanks in triplicate on three non-consecutive days. The IDL is equal to three (3) times the standard deviation of the ten blank measurement results, expressed as µg/L.
- **Method detection limit (MDL):** Prepare seven (7) samples at 3-5x the estimated MDL concentration, as described in the U.S. EPA regulations at 40 CFR Part 136 Appendix B. Note: the MDL samples should be prepared in the Synthetic FGD wastewater matrix. Analyze the MDL standards in triplicate. Calculate the standard deviation of the concentration(s) in µg/L for each analyte. The MDL is calculated as the student's t-value for the degrees of freedom (i.e., 3.143 for 6 degrees of freedom) multiplied by the standard deviation.

Analytical Results

To show the applicability of the NexION 300D ICP-MS for the analysis of FGDW samples, a number of selected tests from the described procedure were carried out.

Instrument and Method Detection Limits

Table 3 shows multielement instrument and method detection limits achievable on the NexION 300D ICP-MS, together with the analyte masses, internal standards and cell mode used. The IDLs were measured in 2% HNO₃/0.5% HCl, while MDLs were measured in a synthetic FGD matrix (dilution corrected). However, because several analytes were present at relatively high concentration in the synthetic FGD, the matrix was not spiked for the MDL measurement. As a result, the MDLs are directly related to the level of contamination in the synthetic FGD matrix.

Table 3. NexION 300D instrument detection limits (IDLs) and dilution-corrected method detection limits (MDLs) achievable in FGDW samples, together with the analyte masses, cell mode and internal standards used.

Analyte/ Mass (amu)	Mode	Internal Standard	IDL (µg/L)	MDL (µg/L)
Al - 27	Standard	Sc	0.040	0.54
V - 51	Reaction	In	0.001	0.02
Cr - 52	Reaction	In	0.005	0.09
Mn - 55	Reaction	In	0.007	0.27
Ni - 60	Collision	Ge	0.005	0.28
Cu - 63	Collision	Ge	0.011	0.30
Zn - 66	Collision	Ge	0.065	1.20
As - 75	Collision	Ge	0.019	0.30
Se - 78	Collision	Ge	0.190	2.20
Ag - 107	Standard	In	0.001	0.03
Cd - 111	Collision	Ge	0.007	0.10
Tl - 205	Standard	In	0.001	0.01
Pb - 208	Standard	In	0.002	0.20

Synthetic FGDW Samples

Table 4 represents a typical synthetic FGDW matrix as defined by the U.S. EPA.

Table 4. Typical concentration of matrix components in a synthetic FGDW sample.

Matrix	Concentration (mg/L)
Chloride	5000
Calcium	2000
Magnesium	1000
Sulfate	2000
Sodium	1000
Butanol	2000

Table 5 shows 3 different sources of synthetic FGDW matrix, emphasizing the very different elemental contamination levels in each solution (dilution corrected).

Table 5. Three different sources of synthetic FGDW matrix, showing different elemental contamination levels.

Analyte/ Mass (amu)	Synthetic FGDW #1 (µg/L)	Synthetic FGDW #2 (µg/L)	Synthetic FGDW #3 (µg/L)
Al - 27	36.4	5.33	7.16
V - 51	5.11	4.31	0.19
Cr - 52	2.97	0.76	1.38
Mn - 55	37.3	25.4	7.02
Ni - 60	4.36	7.44	1.42
Cu - 63	2.35	1.78	3.03
Zn - 66	5.84	27.6	9.26
As - 75	1.11	2.88	1.09
Se - 78	3.10	4.21	3.04
Ag - 107	0.22	2.33	0.31
Cd - 111	3.25	3.92	0.11
Tl - 205	0.19	0.94	0.05
Pb - 208	1.36	9.23	5.37

Table 6 shows the third source (FGDW #3) of synthetic FGDW sample, which has been spiked with 40 µg/L of analytes. Note: this spike was carried out after a 10x dilution and before sample digestion. This is known as the laboratory fortified sample (LFS) spike recovery test, for which the U.S. EPA has set recovery limits of ±30%. It can be seen that the spike recoveries of this LFS are well within the U.S. EPA guidelines.

Table 6. Synthetic FGDW #3 sample, which has been spiked with 40 µg/L of analytes.

Analyte/ Mass (amu)	Synthetic FGDW #3 (µg/L)	Spike Value (µg/L)	Spike Recovery (%)
Al - 27	7.16	40	111.1
V - 51	0.19	40	114.0
Cr - 52	1.38	40	106.8
Mn - 55	7.02	40	111.6
Ni - 60	1.42	40	100.1
Cu - 63	3.03	40	93.0
Zn - 66	9.26	40	94.0
As - 75	1.09	40	110.5
Se - 78	3.04	40	108.3
Ag - 107	0.31	40	90.0
Cd - 111	0.11	40	107.3
Tl - 205	0.05	40	102.6
Pb - 208	5.37	40	94.2

Continuing Calibration Verification (CCV) Standard

The procedure states that the CCV has to be analyzed every 10 samples and also at the end of every analytical run, and every element must achieve a recovery of 85-115%. In addition, the internal standard must achieve a 60-125% recovery over that timeframe. For that reason, it is critical that the instrument drift specification is well within these guidelines to ensure good accuracy and precision. With that in mind, 110 FGDW samples were analyzed over 4.5 hours with the CCV QC standard at 50 µg/L being measured every 10 samples. As can be seen in Figure 2 (Page 7), the stability over that time was well within ±15% limit for all analytes.

The three internal standards (¹¹⁵In, ⁴⁵Sc, and ⁷²Ge) were monitored during the 4.5 hour run. These data are seen in Figure 3 (Page 7) and show that the drift was well within the 60-125% recovery guidelines, as defined by the U.S. EPA.

Sample Results, Matrix Spikes (MS) and Matrix Spike Duplicates (MSD)

Matrix spikes (MSs) were prepared by taking a second aliquot of selected samples and spiking them with the analytes of interest at 40 µg/L. Matrix spike duplicates (MSDs) were prepared by taking a third aliquot of selected samples and spiking them in the same way. The MSs and MSDs are processed in the same manner as the samples. One MS/MSD pair must be measured every 10 samples and the limits are not to exceed 70-130% recovery, and 20% relative percent difference (RPD).

Three real-world FGDW sample results, the MS/MSD and RPD data are shown in Tables 7, 8 and 9 (Pages 7-8). Values are reported in a 10x dilution of the samples, which were all spiked at 40 µg/L. It can be seen that the spikes in all three samples have been recovered well within the U.S. EPA 70-130% recovery guideline (with the exception of Se, which was 132.5%), while RPD values are all less than 6%, which is well below the 20% guidelines set by the U.S. EPA. It should also be noted that the Mn spike recovery was not listed in sample #3 because the spike concentration was too low in comparison with the sample concentration.

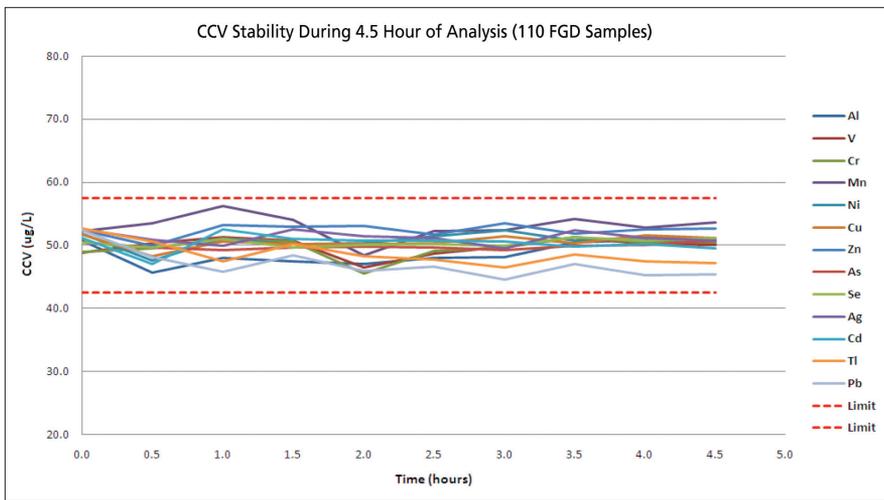


Figure 2. A 4.5 hour stability run of a CCV standard (50 µg/L for all elements) analyzed every 10 real FGDW samples. A total of 110 samples were measured during this time.

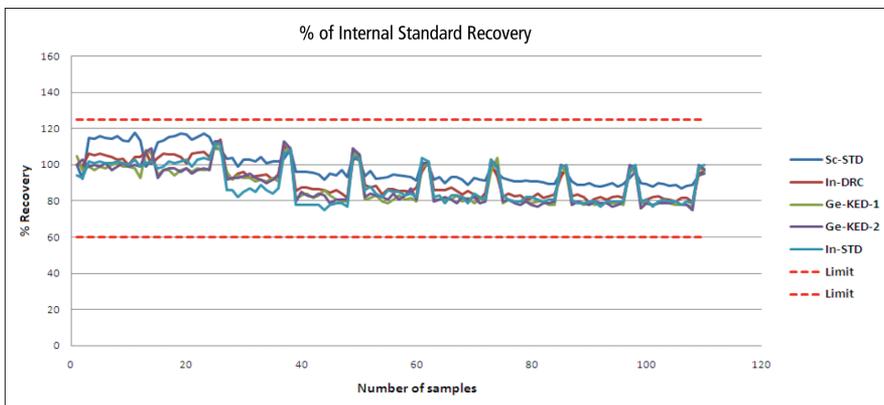


Figure 3. Internal standard recovery in 4.5 hour long stability run.

Table 7. MS/MSD and RPD data for real-world FGDW sample #1.

Analyte/Mass (amu)	Sample #1 (µg/L)	Sample #1 + Spike (µg/L)	Sample #1 + Spike Dup (µg/L)	RPD (%)	Spike Recovery (%)
Al - 27	18.5	58.5	59.1	1.0	99.9
V - 51	1.46	47.1	48.6	3.1	114.2
Cr - 52	1.59	45.1	45.7	1.3	108.7
Mn - 55	10.1	53.7	54.6	1.6	109.0
Ni - 60	0.33	39.8	39.2	1.5	98.6
Cu - 63	0.11	38.4	38.2	0.5	95.6
Zn - 66	1.14	41.4	42.3	2.1	100.7
As - 75	0.50	40.9	40.9	0.1	101.0
Se - 78	47.8	100.8	99.4	1.4	132.5
Ag - 107	<0.003	34.9	33.7	3.3	87.1
Cd - 111	<0.01	40.6	40.8	0.5	101.4
Tl - 205	1.10	38.6	37.5	2.7	93.7
Pb - 208	0.007	34.8	33.7	3.1	86.9

Table 8. MS/MSD and RPD data for real-world FGDW sample #2.

Analyte/Mass (amu)	Sample #2 (µg/L)	Sample #2 + Spike (µg/L)	Sample #2 + Spike Dup (µg/L)	RPD (%)	Spike Recovery (%)
Al - 27	16.6	55.9	56.6	1.3	98.3
V - 51	0.19	46.0	44.8	2.8	114.6
Cr - 52	0.19	43.6	43.2	0.8	108.5
Mn - 55	1.81	44.7	45.0	0.7	107.2
Ni - 60	4.96	45.6	45.0	1.2	101.5
Cu - 63	2.24	39.5	38.4	2.7	93.1
Zn - 66	1.74	40.4	38.8	3.9	96.6
As - 75	0.40	44.8	44.6	0.5	111.0
Se - 78	36.5	84.2	81.1	3.7	119.3
Ag - 107	<0.003	35.6	37.2	4.5	89.0
Cd - 111	<0.01	42.0	40.4	3.9	105.1
Tl - 205	0.03	42.1	43.6	3.6	105.2
Pb - 208	0.09	39.3	41.2	4.6	98.1

Table 9. MS/MSD and RPD data for real-world FGDW sample #3.

Analyte/Mass (amu)	Sample #3 (µg/L)	Sample #3 + Spike (µg/L)	Sample #3 + Spike Dup (µg/L)	RPD (%)	Spike Recovery (%)
Al - 27	4.82	40.2	40.9	1.7	88.5
V - 51	0.04	44.3	44.1	0.4	110.7
Cr - 52	0.09	42.3	42.7	1.0	105.5
Mn - 55	2191	2194	2227	1.5	N/A
Ni - 60	0.74	40.3	39.3	2.3	98.8
Cu - 63	0.04	35.6	35.3	0.7	88.9
Zn - 66	0.42	36.3	37.1	2.1	89.7
As - 75	0.60	43.8	43.5	0.7	108.0
Se - 78	17.8	64.0	60.5	5.5	115.5
Ag - 107	<0.003	34.1	34.6	1.6	85.2
Cd - 111	<0.01	40.7	40.5	0.5	101.7
Tl - 205	1.10	44.1	44.3	0.5	107.5
Pb - 208	<0.02	38.7	39.3	1.5	96.7

N/A = Not applicable, because the spike concentration was too low compared to the sample concentration.

Conclusion

Flue gas desulfurization wastewater samples are among the most difficult samples to analyze by ICP-MS. The extremely high levels of sulfates, chloride, alkali/alkaline earth/heavy metals and organic species in the sample can cause a multitude of problems. Some of these problem areas include very high concentrations of matrix components that produce severe sample transport effects, unless the necessary sample delivery steps are taken. In addition, the heavy matrix has the potential to cause serious signal drift by depositing material on the interface cones. The extremely high levels of carbon can also impact the ionization temperature in the plasma, leading to suppression or enhancement effects on the analytes of interest. And finally, the high chloride, sulfate and carbon levels will generate ions in the plasma that combine with argon-, solvent- and acid-based species to produce severe polyatomic spectral interferences on many of the analytes.

For these reasons, it is absolutely critical that the analyst has all the necessary tools to minimize the effects of all these potential interferences. The investigation has shown that the NexION 300D ICP-MS has many of these advanced interference reduction tools to successfully analyze FGDW waters according to U.S. EPA methodology. From the discrete, fast sampling, through the Triple Cone Interface (TCI) to minimize drift, to the Universal Cell reducing or removing many severe spectral interferences, the system can generate a high-quality, stable signal over many hours of operation. And finally, the Quadrupole Ion Deflector (QID) allows for the maximum throughput of ions, while maintaining extremely low background levels. This study has demonstrated that the NexION 300D ICP-MS, coupled with an SC-DX FAST system, is ideally suited to cope with the analytical demands of this very difficult application.

References

1. U.S. EPA Air Pollution Control Technology Fact Sheet related to the FGDW process –<http://www.epa.gov/ttnatc1/dir1/ffdg.pdf>
2. U.S. EPA Steam Electric Power Generating Point Source Category: Final Detailed Study Report (EPA 821-R-09-008) – <http://water.epa.gov/scitech/wastetech/guide/upload/finalreport.pdf>
3. Inductively Coupled Plasma/Mass Spectrometry for Trace Element Analysis in Flue Gas Desulfurization Wastewater: EPA Office of Water Engineering & Analysis Division, May 2011.
4. Trace Metals Determination in Flue Gas Desulfurization Waters: Optimization of Dynamic Reaction Cell ICP-MS. EPRI, Palo Alto, CA: 2009. 1017978 – http://my.epri.com/portal/server.pt?Abstract_id=00000000001017978
5. U.S. EPA Method 200.8: "Determination of Trace Elements in Waters and Wastewaters by Inductively Coupled Plasma – Mass Spectrometry," 1994 – <http://www.epa.gov/sam/pdfs/EPA-200.8.pdf>
6. U.S. EPA Method 1638. "Determination of Trace Elements in Ambient Waters by Inductively Coupled Plasma – Mass Spectrometry," 1996 – http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2007_07_10_methods_method_1638.pdf
7. The 30-Minute Guide to ICP-MS – PerkinElmer, Inc.
8. S.D. Tanner, V.I. Baranov, Atomic Spectroscopy, 20, 2, 45-52, (1999).
9. Improving Throughput of Environmental Samples by ICP-MS Following EPA Method 200.8, ESI Application Note – <http://www.icpms.com/products/sc-fast-enviro.php>
10. Improved Performance in the Analysis of Drinking Waters and Wastewaters by U.S. EPA Method 200.8 with an SC-FAST System – PerkinElmer, Inc.
11. The Analysis of Drinking Waters by U.S. EPA Method 200.8: Using the NexION 300D ICP-MS in Standard, Collision and Reaction Modes – PerkinElmer, Inc.

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