GLASS EXPANSION
Quality By Design

Application Note

Considerations when Analyzing Real-World Samples by ICP Spectrometry

Dealing with a sample matrix high in total dissolved solids (TDS) is a common challenge for ICP spectrometry and generally most "real samples" analyzed by ICP laboratories contain considerable concentrations of TDS. These sample types include soils, sludge, wastewater, brines, high acid digests and fusions. The challenges associated with these samples include interrupted runs, signal drift, clogged nebulizers, shortened torch life, and greater interferences.

Due to the popularity of these analyses the very first issue of the Glass Expansion Newsletter focused on methods to alleviate these challenges and improve ICP performance.[1] In June of 2010 we released a follow up application note, covering both improvements in ICP design and new product releases pertinent to high salt matrices.[2] Seven years have passed since our last "high TDS" application note and during this time frame there have been several new additions and updated designs to the Glass Expansion "high TDS" product line, in addition to new ICP spectrometer releases. Our current issue highlights the performance of these new sample introduction options, in addition to providing detailed maintenance procedures to reduce the frequency of replacement and help maintain the performance of the ICP sample introduction system. We also included an appendix with references from a wide range of ICP manufactures covering high TDS applications utilizing the newest instrument releases.

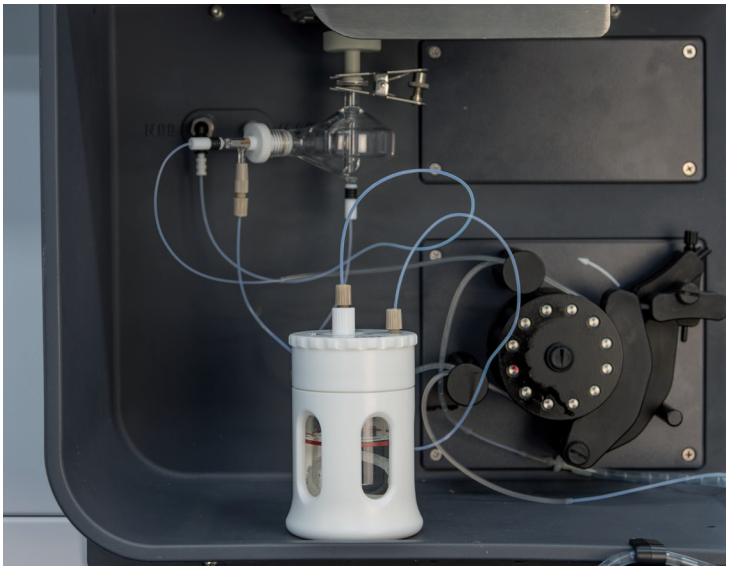
The goal of this issue of the Glass Expansion Newsletter is to provide up-to-date guide and useful tutorial for analyzing real samples by ICP spectrometry.

Sample Introduction System

An argon humidifier is one of the most important accessories for ICP-OES and ICP-MS analyses involving samples with high concentrations of TDS. The added moisture in the nebulizer gas helps to reduce salt deposits in the nebulizer and torch injector, allowing uninterrupted ICP operation. In addition to the argon humidifier, a large bore injector is recommended, typically, greater than 1.5mm ID for radial view ICP-OES instruments and greater than 2.0mm ID for axial view ICP-OES and ICP-MS instruments. Due to the rapid devitrification of quartz in the presence of high TDS, a demountable ICP torch is preferred to reduce replacement costs. A nebulizer capable of handling a high amount of TDS should be chosen and combined with a baffled cyclonic spray chamber to eliminate large droplets from reaching the torch.

An example of a complete High TDS application kit for the Agilent 5100 SVDV ICP-OES is shown in Figure 1. Below we will describe in detail the characteristics of each of these essential high TDS components.

Figure 1. Glass Expansion High TDS Package for Agilent 5100 ICP-OES.



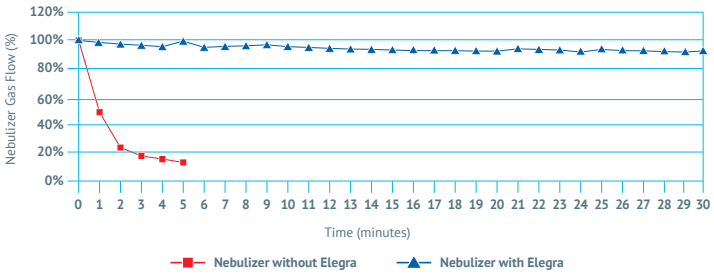
Argon Humidifier

Figure 2. Elegra Argon Humidifier

The Elegra™ argon humidifier was released in February 2016[3], offering an upgraded design to the Capricorn™. The elegant design of the Elegra results in a very compact accessory (Figure 2), making it easy to fit every ICP model without overcrowding the sample compartment and providing simple installation. The Elegra utilizes highly efficient membrane technology to add moisture to the argon as it flows through the inert metal-free construction. The device runs at atmospheric pressure and does not require heating or electric power, as required by other manufacturers. The Elegra is also configured with a bypass switch so that the operator can turn humidification on and off without connecting or disconnecting any tubing.

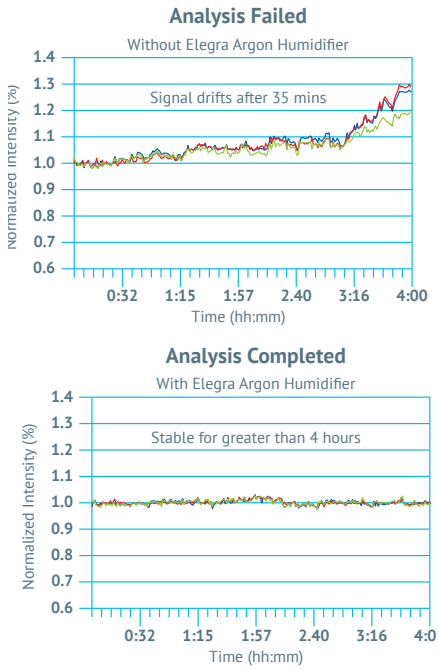
To evaluate the performance of the Elegra, a nebulizer stress test was completed aspirating a 25% NaCl solution while monitoring the nebulizer gas flow with and without the Elegra (Figure 3). A decrease in gas flow is a good indicator of a nebulizer that is clogging. Note a nebulizer with a TDS tolerance rating of only 5% was used to illustrate the advantage of the Elegra. As a worst case test, the salt solution was aspirated continuously, with no rinsing. As expected, without the Elegra, the nebulizer was completely clogged after only 5 min. In contrast, the same nebulizer with the Elegra, held a relatively constant gas flow throughout the entire test (over 30 min). A similar result was also observed with the injector, which is detailed elsewhere.[3]

Figure 3. Elegra Nebulizer High TDS Stress Test (25% NaCl)



Even when a proper high TDS nebulizer is chosen, some matrices like lithium metaborate fusions can pose a challenge due to the very high amount of TDS. The stability of three internal standard (IS) lines were compared with and without the Elegra (Figure 4) by an ICP contract laboratory running a lithium metaborate method. Without the Elegra the IS signals begin to drift after 35 min, eventually resulting in a failed analysis (> 10% drift). With the Elegra there is negligible variation in IS signal over a period of 4 hours. A significant reduction in the required nebulizer maintenance was also observed, going over two months without cleaning as opposed to weekly cleaning without the Elegra.

Figure 4. Internal Standard Stability in 0.5% Lithium Metaborate

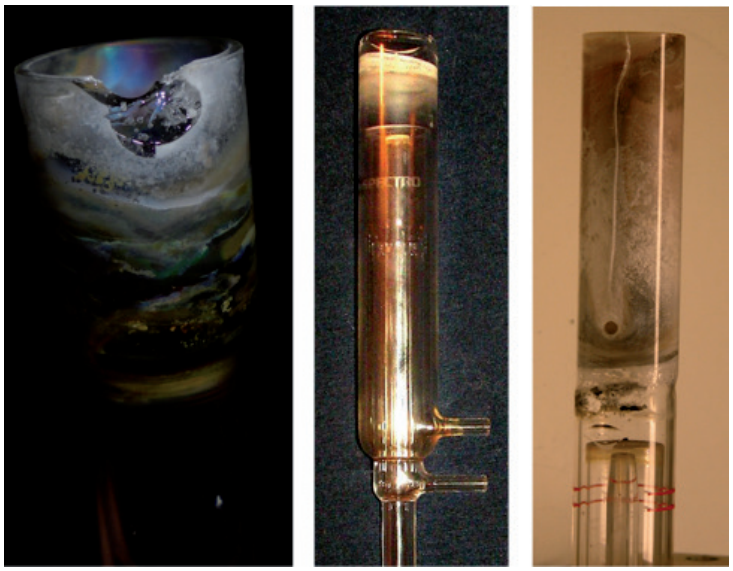


A Dual Channel Elegra is also available which provides the ability to humidify both the nebulizer gas and an auxiliary or dilution gas. A dilution gas accessory is now a standard option on some ICP-MS instruments[4,5,6] (this is an alternative approach to an inline or offline liquid dilution of the samples). High TDS samples need to be diluted for ICP-MS analysis to prevent the rapid build-up of salt deposits on the interface cones, which would otherwise result in signal drift and frequent cleaning. The inline aerosol dilution of the sample prior to introduction into the plasma, allows for improved analysis of high matrix samples by ICP-MS. The dual channel Elegra prevents nebulizer and injector blockage due to salt build-up and as a bonus, the moisture of the dilution gas reportedly ensures a high thermal conductivity resulting in improved ionization.[5]

Torch Selection

The combination of high temperature and salt deposits causes a quartz torch outer tube to devitrify; examples are shown in Figure 5. The disadvantage of a single-piece torch is that it is a relatively high cost consumable item that requires regular maintenance and replacement, particularly with more demanding samples, such as high TDS. This is because the whole torch must be replaced when just the outer tube suffers from devitrification.

Figure 5. Common wear from high temperature and presence of high TDS.



The Glass Expansion D-Torch (Figure 6), is an economical alternative to the single piece or semi-demountable quartz torch. The D-Torch incorporates a ceramic intermediate tube for greater robustness and provides the analyst with an outer tube that can be replaced when it fails rather than replacing the entire torch. The D-Torch also features an interchangeable injector, allowing the analyst to install a specific injector (material and internal diameter) for each application whether it be for aqueous, organics, high TDS or HF.

Figure 6. Glass Expansion D-Torch fully demountable torch, example shown for Thermo iCAP Duo.

P/N: 30-808-2862

P/N: 31-808-2840

P/N: 31-808-2836

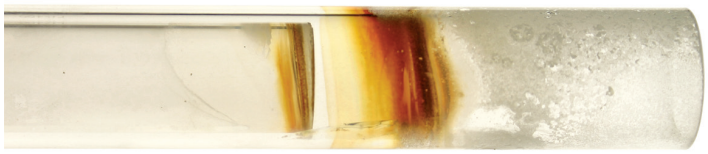
P/N: 31-808-2835

Unique to the D-Torch is an optional ceramic outer tube, which is of particular benefit for the analysis of high TDS sample matrices because the Sialon material does not devitrify. In Figure 7 we compare a quartz outer tube with a ceramic outer tube, both of which have been exposed to 6 hours of a 10% NaCl analysis. You can clearly see that there is no change to the integrity of the ceramic outer, whereas the quartz is severely devitrified.

Figure 7. A comparison of resistance to devitrification when exposed to high salt matrix.

6 HOURS OF RUNNING 10% NaCl

Quartz Outer Tube



Ceramic Outer Tube

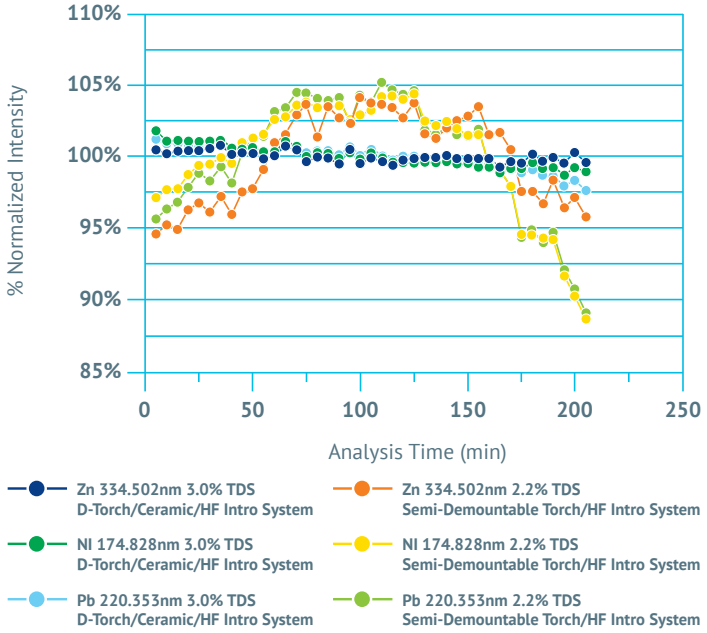
A detailed performance evaluation of the fully ceramic D-Torch was presented in a 2010 application note[7] by Thermo Fisher Scientific. In this report, the D-Torch exhibited exceptional stability in the presence of 3 % NaCl and provided equivalent analytical performance to the standard quartz torch on the iCAP 6000 Radial ICP-OES (Table 1)[7] In another report[8] the D-Torch was utilized for a homogeneity assessment of custom blend Certified Reference Materials (www.inorganicventures.com). An important criterion for a homogeneity assessment is that the CRM remain undiluted; at 100 to 10,000 ppm this matrix results in significant devitrification of the quartz. Figure 8 highlights the improved signal stability achieved with the ceramic D-Torch versus a quartz semi-demountable torch. The complete report can be found in our October 2013 Newsletter.[8]

Table 1: Detection limit comparison between the Ceramic D-Torch and standard quartz torch

	Detection Limit (µg/L)	
Element (λ)	Radial EMT Torch	Radial Ceramic D-Torch
Al 167	1.6	1.1
Ba 455	0.07	0.12
Cu 324	0.88	0.62
K 766	25.5	11.7
Mg 279	0.05	0.05
Mn 257	0.36	0.25
Ni 221	1.6	1.3
P 177	5.1	5.0
Zn 213	0.23	0.28

Data taken from Thermo Fisher Scientific Technical Note # 43202

Figure 8. Signal stability obtained from a homogeneity assessment of a custom blend CRM when using the fully ceramic D-Torch compared to a semi-demountable quartz torch.



New D-Torch models have recently been released for the Agilent 5100 and 5110 ICP-OES, PerkinElmer Avio ICP-OES, SPECTRO Arcos II and SPECTRO Blue ICP-OES (Figure 9). These new D-Torch models feature the same auto aligning and locking mechanism of the corresponding standard torches, but in a robust demountable design which is compatible with a ceramic outer tube. The D-Torch is currently available for a range of ICP-OES and ICP-MS instruments, see the Glass Expansion website for a complete list.

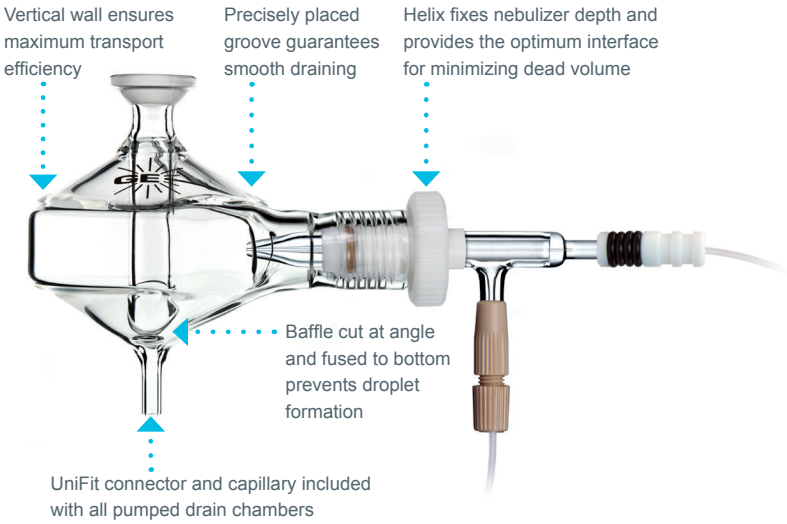
Figure 9. New D-Torch releases.

Agilent 5100/5110 | PerkinElmer Avio | SPECTRO Arcos II/ SPECTRO Blue

Spray Chamber Selection

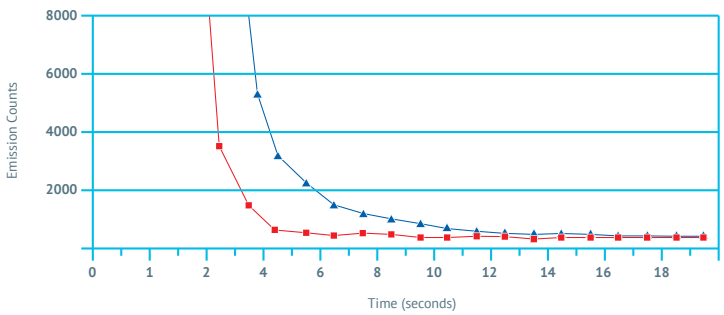
Glass Expansion spray chambers are manufactured with specific design features to provide the utmost performance. The design characteristics of the Twister™ cyclonic spray chamber are detailed in Figure 10. Unique to all Glass Expansion spray chamber designs is our proprietary Helix™ zero dead volume nebulizer interface. Eliminating the dead volume around the nebulizer seal leads to faster washout times and higher sample throughput.

Figure 10. Glass Expansion Twister baffled cyclonic spray chamber design features.



This improvement in washout is shown in Figure 11, where a 10 ppm standard washes out in 4 seconds with the Twister compared to 16 seconds with a "Brand-X" spray chamber.[9] Washout is especially important with high matrix samples, as high concentrations will take longer to completely rinse out.

Figure 11. 10 ppm Mo washout Comparison between Helix and non-Helix spray chambers.



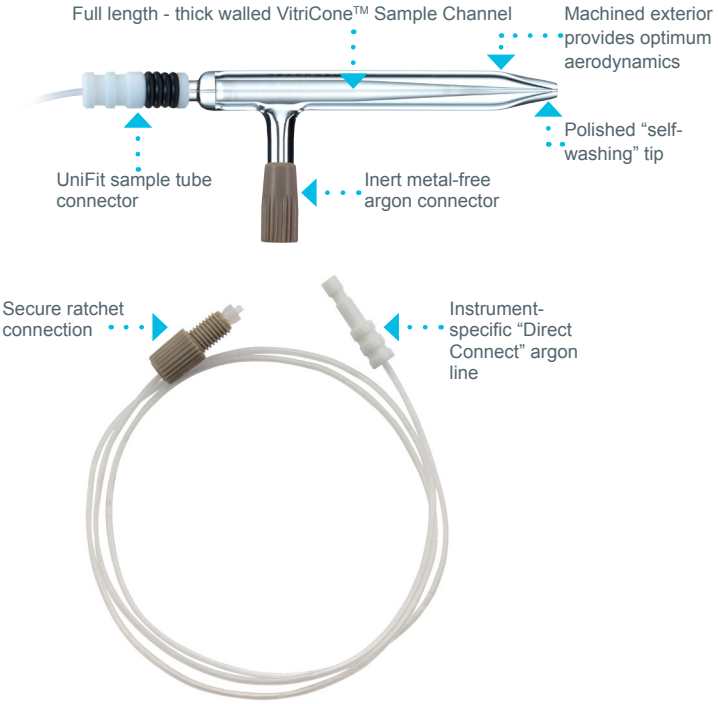
The Twister cyclonic spray chamber also features a central transfer tube, which acts as a secondary droplet filter to reduce the mean droplet size. This helps to reduce the sample load within the plasma without compromising detection limits and improving precision (% RSD). The reduced sample load helps to increase torch life, slow salt build-up at the injector tip, and decrease the frequency of cleaning ICP-MS interface cones. These features make a baffled cyclonic spray chamber, like the Twister, the ideal choice for a high TDS application.

Nebulizer Selection

When dealing with high TDS samples, we recommend using the SeaSpray™, Glass Expansion's worldwide market-leading high performance concentric glass nebulizer. The SeaSpray comprises a unique self-washing tip designed to prevent crystal growth, providing a tolerance of up to 20% TDS. The SeaSpray's popularity is due to its ability to offer outstanding nebulization efficiency for trace level analyses combined with excellent precision and a high tolerance to TDS.

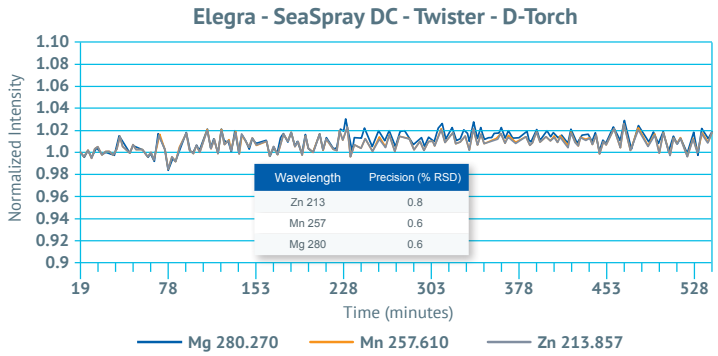
In 2016 the Direct Connect (DC) nebulizer product line was released, combining the benefits of our proprietary UniFit™ zero dead volume sample connector and full-length VitriCone capillary[10] with an improved gas connection assembly. The features of the SeaSpray DC nebulizer are summarized in Figure 12.

Figure 12. Features of SeaSpray DC Nebulizer.



To evaluate the performance of the SeaSpray DC nebulizer a 1 ppm multi-element standard was prepared in a 3.5 % NaCl matrix and aspirated at 1 mL/min for 9 hours with no rinsing. The test was carried out on an Agilent 5100 SVDV ICP-OES instrument. The combination of the SeaSpray DC nebulizer, Twister spray chamber, ceramic D-Torch, and Elegra argon humidifier provided exceptional stability (Figure 13). A measurement was taken approximately every 3 mins over a period of 9 hours, while a precision (%RSD) of less than 1 % was maintained throughout the experiment.

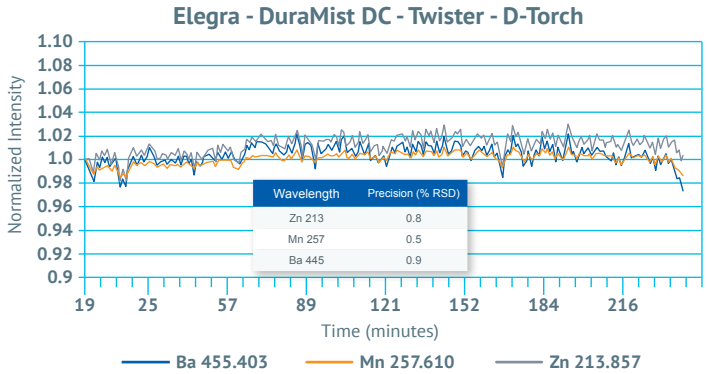
Figure 13. Long term stability test, 9 hour analysis of 1 ppm standard in 3.5 % NaCl.



To complement the SeaSpray, the inert DuraMist nebulizer was introduced in 2011.[11] The DuraMist is also a concentric nebulizer, designed with a PEEK capillary insert and PEEK body capable of handling up to 30% TDS and up to 5% hydrofluoric acid (HF). The strength and rigidity of the PEEK material allows the DuraMist to be manufactured to very tight tolerances, enabling it to closely match the performance of the SeaSpray, but in an inert design.

To evaluate the performance of the DuraMist DC nebulizer a similar experiment was conducted, only this time a 1 ppm multi-element standard was in a 10.0 % NaCl matrix and aspirated at 1 mL/min for 4 hours with no rinsing. The DuraMist DC nebulizer was combined with the same "High TDS" application kit that was used in the SeaSpray experiment, with a measurement taken every minute over a period of 4 hours (Figure 14). Results with the DuraMist are also exceptional, as a precision (%RSD) of less than 1 % was maintained throughout the experiment.

Figure 14. Long term stability test, 4 hour analysis of 1 ppm standard in 10.0 % NaCl.



Reducing Sample Load and Increasing Washout Efficiency

In our evaluation of the SeaSpray and DuraMist nebulizers a rinse was not utilized in-between each sample. The rinse was purposely eliminated from the ICP method to focus on each nebulizer's high tolerance to TDS. However, with any high TDS application it is recommended that you increase your rinse time between samples to provide improved performance and long term stability. It is also recommended that you reduce the sample uptake rate to as low as your detection limits allow to minimize the amount of sample transported to the plasma. Lowering the sample uptake will reduce the rate of devitrification to the quartz torch and frequency of cleaning the ICP-MS cones.

However, longer rinse times combined with a lower sample uptake can add significant time to your analysis. Some of this additional time can be easily eliminated from your method with the Niagara CM Rapid Rinse accessory (Figure 15), which begins rinsing the nebulizer and spray chamber the instant the sample measurement is completed and continues to rinse until the next sample is ready. This economical and simple 4-port switching valve carries out the rinse cycle during the time that is usually wasted waiting for the sample to reach the nebulizer (commonly referred to as the uptake delay) and subsequently void to waste. The fast pump option that is typically employed to reduce the uptake delay time puts excess stress on the nebulizer and ICP sample introduction system by running at high flow rates that exceed the recommended operating conditions. With the Niagara the fast pump can be employed with no negative effects, since the sample is directed to waste during the uptake delay. The Niagara rinse tubing calculator will also calculate the correct size

rinse tubing to be used so that a constant flow to the plasma can be achieved throughout the analysis. The performance of the Niagara CM Rapid Rinse was highlighted in our June 2016 Newsletter.[12]

The typical time saved with the Niagara is around 30% as shown in Table 2. With the Niagara you also minimize the amount of sample introduced into the plasma, since the valve switches immediately after the read is complete directing excess sample to waste, bypassing the sample introduction system. This feature can drastically reduce your consumables costs, particularly for challenging sample matrices like high TDS where the ICP torch and/or ICP-MS cones require frequent cleaning and suffer from a shorter life.

Figure 15. Niagara CM Rapid Rinse Accessory

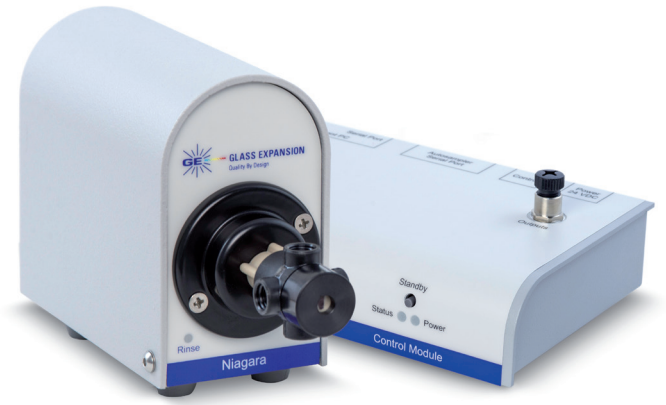


Table 2. Method timing with and without the Niagara Rapid Rinse

	Without Niagara Rapid Rinse	With Niagara Rapid Rinse
Total Time (sec)	200	129
Improvement	N/A	35%
Samples per hour	18	28

ICP-MS Cones

When dealing with a high TDS matrix analyzed by ICP-MS, Pt cones are often preferred in place of Ni. The Pt insert runs hotter than Ni, which slows the build-up of salts at the orifice. This allows the ICP-MS analyst to run for longer periods of time before cone maintenance is required. Unlike Ni cones, Pt cones can be economically refurbished several times, as long as the orifice and tip are still in reasonably good condition. This provides a high TDS ICP-MS laboratory with a significant cost savings.

Glass Expansion manufactures ICP-MS cones to the same exacting standards as all of our products and they are guaranteed to perform to your satisfaction. Our manufacturing plant includes four CNC machines and an electron beam welder allowing us to provide you with the tightest manufacturing specifications.

We supply cones for all of the popular ICP-MS models including the Agilent 7500, 7700, 7800, 7900 8800 and 8900, the PerkinElmer Elan and NexION, and the Thermo Fisher X Series, Element and iCAP Q. We also provide a Free Pt refurbishment service; visit the Glass Expansion website to learn more.

Maintenance Procedures

Nebulizer

To keep your nebulizer in good condition, always finish a run by nebulizing a mildly acidic blank solution followed by deionized water for several minutes. This ensures that sample deposits do not form inside the nebulizer when the solvent dries out.

If the nebulizer becomes blocked with salt build-up, the Eluo Nebulizer Cleaning Tool provides a safe and convenient way to remove the blockage from your Glass Expansion nebulizer. Never attempt to remove a blockage with wires or probes; irreparable damage is likely to result.

Glass Expansion Eluo designs:

- Eluo for glass concentric nebulizers (SeaSpray, Conikal, MicroMist, Slurry) – P/N 70-ELUO
- Eluo for inert concentric nebulizers (OpalMist, DuraMist, PolyCon) – P/N 70-ELUO-OPD

If there are salt deposits that cannot be removed with a quick backflush using the Eluo, we recommend the following procedure:

1. Initially flush your nebulizer with warm water* using the Eluo.
2. Soak the nebulizer tip in a 25% solution of Fluka RBS-25 (P/N FLUKA25) for 24 hours. Use the Eluo to make sure the Fluka RBS-25 solution fills the nebulizer. An initial flush of 25% Fluka using the Eluo may be required.
3. After 24 hours, flush the nebulizer 3 times with warm water* using the Eluo.
4. Stubborn deposits may require an additional soaking for 2 hours with a 5% nitric acid solution.
5. Flush 3 times with warm water* using the Eluo.
6. For faster drying, flush again with methanol.

* Warm water only recommended for use with glass or quartz nebulizers.

A helpful video tutorial on nebulizer maintenance using the Eluo can be found at: https://youtu.be/587QFobdQgE

Particulates

In order to prevent any issues with clogs or blockages due to particulates (undissolved solids in your samples), install a re-usable Inline particle filter (P/N 70-803-1108) which provides a simple and effective way to eliminate the risk of particulates getting trapped in your nebulizer or sample capillary tubing. It incorporates a re-usable 120 micron PEEK filter and is suitable for use with 1/16 inch (1.6mm) or 1.3mm OD sample tubing. The filter can easily be cleaned by back-flushing using an adaptor (P/N 70-803-1160) connected to the Eluo Nebulizer Cleaning Tool.

The best cleaning procedure for the inline filter is to do a quick soak (~5min) in a 25% Fluka RBS-25 solution, sonicate the assembly for ~5min, then backflush 3 times with warm DI water using the Eluo tool and back flushing adapter. If you do not wish to use the Fluka RBS-25, a similar glassware cleaner, or even dilute acid will help.

Glass Expansion's Quality Assurance Kit (P/N KT-1136) combines the re-usable inline filter, back flushing adapter, Eluo nebulizer cleaner and TruFlo sample monitor providing your ICP laboratory with all the tools necessary to protect and maintain your ICP nebulizer. The addition of the TruFlo sample monitor provides a continuous

real-time display of the liquid flow to the nebulizer. The TruFlo can be used to alert the analyst when the inline filter needs to be back-flushed in addition to optimizing nebulizer conditions.

Spray chamber

To avoid the risk of breakage, washing glass spray chambers in an ultrasonic bath is not recommended. If you notice a degradation in performance (such as poorer precision or detection limits) or droplets accumulating on the walls of the spray chamber, it is time to clean the spray chamber. Aspirating a 2.5% Fluka RBS-25 solution for 15 minutes may be sufficient to recover the performance. Otherwise, the spray chamber should be soaked overnight in a 25% Fluka RBS-25 solution and rinsed the following day with DI water.

Torch

As with the nebulizer, it is good practice to always finish use of a torch by nebulizing a mildly-acidic blank solution for several minutes. This ensures that sample deposits or crystals don't form inside the torch injector bore when the solution inside the injector dries out.

Salt deposits can occur near the end of the outer tube and should be regularly removed to prolong the torch life. This is best accomplished by soaking the torch or outer tube in a 25% solution of Fluka RBS-25. We recommend that you do not leave the torch in an ultrasonic bath as this may damage the quartz. If deposits on the outer tube is a persistent problem, in some cases, a torch with a shorter outer tube may be available. Although this may result in a small loss of sensitivity, it can also lead to a significant improvement in torch life. The other alternative is a fully ceramic D-Torch which is less likely to accumulate salt deposits for reasons discussed previously.

Conclusions

If you want the best performance your ICP-OES or ICP-MS can provide, it is essential that you choose the proper sample introduction system to meet the demands of your sample types. In this application note, a complete sample introduction package was presented to improve ICP performance in a high TDS sample matrix.

An easy way to eliminate drift, interrupted runs and frequent maintenance to your ICP sample introduction system is to add the Elegra argon humidifier. The D-Torch offers an affordable, robust ICP torch design while greatly reducing torch consumable costs. The optional ceramic outer tube for the D-Torch provides a significant improvement in torch life and stability in the presence of high TDS. Combining either the SeaSpray or DuraMist nebulizer with the Twister spray chamber will provide optimum sensitivity and exceptional long-term precision even in the presence of high TDS. The Niagara CM Rapid Rinse accessory provides a simple low-cost approach to improving ICP productivity and washout efficiency while minimizing sample consumption. Proper care and regularly scheduled maintenance of your sample introduction system can help to maintain optimum performance and increase lifetime. The Fluka RBS-25 solution is an essential cleaning solution that every high TDS ICP laboratory should have on hand. It provides an excellent cleaning reagent for your entire sample introduction system.

Glass Expansion's intimate understanding of the relationship between the various sample introduction components, together with our expertise in manufacturing high quality nebulizers, spray chambers, torches, ICP-MS cones and ICP accessories, means that we can offer you a complete solution regardless of your sample matrix. Visit us at www.geicp.com or contact us at equiries@geicp.com to find the best solution for your ICP laboratory.

References

1. Glass Expansion June 2003 Newsletter, "Determination of Trace Metals in Seawater by ICP-AES."
2. Glass Expansion June 2010 Newsletter, "Dealing with High Salt Matrices."
3. Glass Expansion February 2016 Newsletter, "The Elegra Argon Humidifier: Uninterrupted and Maintenance-Free ICP Operation."
4. Agilent Technologies Application Note # 5991-4257EN, "Performance of Agilent 7900 ICP-MS with UHMI for high salt matrix analysis," (2014)
5. Perkin Elmer Product Note # 012394-01, "All Matrix Solution System for the NexION ICP-MS." (2015)
6. Thermo Fisher Scientific Technical Note # 43202, "Analysis of High Martix Samples using Argon Gas Dilution with the Thermo Scientific iCAP Q ICP-MS." (2016)
7. Thermo Fisher Scientific Technical Note # 43053, "Radial Demountable Ceramic Torch for the Thermo Scientific iCAP 6000 Series ICP Spectrometer." (2010)
8. Glass Expansion October 2013 Newsletter, "How to Achieve High Accuracy with Difficult Samples."
9. Glass Expansion October 2014 Newsletter, "ICP Spray Chamber Update."
10. Glass Expansion June 2013 Newsletter, "A Nebulizer Update."
11. Glass Expansion October 2011 Newsletter, "Evaluation of a New High Performance Inert Nebulizer."
12. Glass Expansion June 2016 Newsletter, "A Simple, Low Cost Approach to Improving ICP Productivity."

Appendix - Instrument Manufacturers References

Typically, with each Newsletter article we include an “Instrument News” section. Seeing that “High TDS” applications are such a popular topic in ICP spectrometry, we thought it would be valuable to list several ICP manufacturer application notes addressing this topic. This section provides a list of application notes that supplement the information presented here. Addition details from each manufacturer highlight what adjustments can be made to the ICP operating parameters to improve ICP performance. This section may also be helpful if you are in the market for a new ICP-OES or ICP-MS instrument.

Agilent 5100/5110 ICP-OES:

1. Publication # 5991-4854EN, “Benefits of a vertically oriented torch - fast, accurate results, even for your toughest samples.” 2014
2. Publication # 5991-7914EN, “Analysis of Four Elements (Ca, Mg, Si, Sr) in Brine Using the Agilent 5100 ICP-OES.” 2017

Agilent 7900 ICP-MS:

1. Publication # 5991-4257EN, “Performance of Agilent 7900 ICP-MS with UHMI for high salt matrix analysis.” 2014

Analytik Jena PQ 9000 ICP-OES:

1. Analytik Jena Application Note, "Brine Analysis by HR ICP-OES on PlasmaQuant PQ 9000 Elite." 2014
2. Analytik Jena Application Note, "Direct Sea Water Analysis by HR ICP-OES." 2015

Horiba Ultima 2 ICP-AES:

1. Application Note 48 “Brine Analysis with the ULTIMA 2 ICP-AES.”

PerkinElmer Avio and Optima ICP-OES:

1. PerkinElmer Application Note # 012881-01, “Meeting the Challenges of Soil Analysis with the Avio 200 ICP-OES.” 2016
2. PerkinElmer Application Note # 009935-01, “ICP-OES Analysis of FeCr Alloys Prepared by Sodium Peroxide Fusion.” 2011

PerkinElmer NexION ICP-MS:

1. PerkinElmer Product Note # 012394-01, “All Matrix Solution System for the NexION ICP-MS.” 2015

SPECTRO Arcos II ICP-OES:

1. SPECTRO ICP Report 62, “Analysis of 200 g/L NaCl-Solutions by ICP-OES with Radial Plasma Observation.”

Shimadzu 9800 ICP-AES:

1. Shimadzu Application News # SSI-ICP-003, “Analysis of Highly Mineralized Aqueous Solutions by ICP-AES, a Non-dilution Method with Multi-wavelength Calibration for Major, Minor and Trace Elements.” 2016

Teledyne Prodigy 7 ICP-OES:

1. Teledyne Leeman Labs Application Note AN 1305, “U.S. EPA SW-846 Method 6010C Using the Prodigy7 HighDispersion ICP Introduction.” 2015

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