Advantages of the New Conical Torch for ICP Spectrometry

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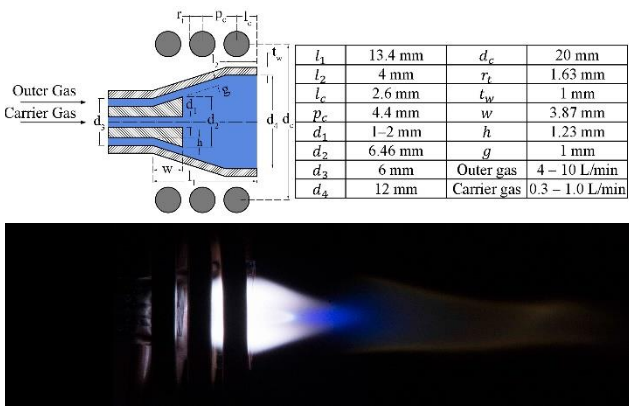
Abstract: The new conical ICP torch is a suitable replacement for conventional torches due to several advantages. Primarily, it provides higher excitation temperature, higher electron number density, higher robustness, lower matrix interference, and equivalent or better detection limits, while working with 50 – 70% power and argon gas. In addition, the new torch offers shorter sample residence time, improved flow pattern, and better resistance against extinguishing factors. All these features pave the way for new possibilities in the emerging applications of ICP-OES and ICP-MS technologies.

Keywords: Conical ICP torch, Sample residence time, ICP-MS, ICP-OES, Particle trajectory, Plasma stability

1. Introduction

Recently, we developed a new generation of inductively coupled plasma (ICP) torch which is capable of working with 50 – 70% reduced gas and power consumption due to its unique conical geometry, while exhibiting superior analytical performance compared with conventional torches [1, 2] . Using optical spectrometry, it has been shown that the conical torch produces a plasma with around 1000 – 1700 K higher rotational and excitation temperature, 5 times higher electron number density, 3 times higher robustness (MgII/MgI ratio), lower matrix effects, and equivalent or better multi-element detection limits. The improved figures-of-merit are believed to be due to the 4 times higher power density inside the conical torch [1, 2].



l_1	13.4 mm	d_c	20 mm
l_2	4 mm	r_t	1.63 mm
l_c	2.6 mm	t_w	1 mm
p_c	4.4 mm	w	3.87 mm
d_1	1–2 mm	h	1.23 mm
d_2	6.46 mm	g	1 mm
d_3	6 mm	Outer gas	4 – 10 L/min
d_4	12 mm	Carrier gas	0.3 – 1.0 L/min

Fig. 1. (Top) Geometrical and operational parameters of the conical torch. (Bottom) Image of the conical torch in operation (power: 900 W, outer gas: 7 L/min) while a titanium standard solution is being injected into the plasma.

Fig. 1 shows the geometrical and operational parameters of the conical torch. Also, in this figure the conical torch is shown in operation while a Ti standard solution is being introduced to the plasma via the injector tube. Aside from the excellent figures-of-merit mentioned above, the conical torch offers additional features which were not previously achievable with conventional Fassel-type torches. Here we briefly cover these advantages and their potential importance for emerging applications in ICP-OES and ICP-MS.

2. Sample Residence Time

The residence time of sample species inside the plasma directly influences the analytical performance of the torch. If the residence time is too short, the ionization or excitation of sample species will be incomplete which, in turn, leads to loss of signal and sensitivity. On the other hand, if the residence time is excessively long, the cloud of ionized/excited particles gradually diffuses into the bulk of the plasma and away from the central axis of the torch, as shown by others [3]. As a result, part of the sample, and with it signal intensity, will be lost. This is especially important when performing single particle/cell analysis where each particle/cell is unique and carrying precious information regarding its composition, size, and other characteristics [4-10].

To keep the diffusion of sample species to a minimum, it is therefore desirable to ionize and excite them in the shortest possible distance inside the plasma. Using both computer simulations and experimental measurements it has been shown that the new torch is able to ionize and excite the sample species between 2 to 3 times faster than the conventional Fassel torch [2, 11]. In addition to the higher excitation temperature and electron number density of the plasma, compactness of the torch and higher gas velocity is also a contributing factor to this enhancement.

Table 1. Computer-simulated values of residence time and maximum axial LTE temperature, for the conical and Fassel torches at various operating conditions [2].

Torch	Power (W)	Outer gas (L/min)	Intermediate gas (L/min)	Carrier gas (L/min)	Injector i.d. (mm)	Residence time (µs)	Max. axial Temperature (K)
Conical	900	7	-	0.5	1	653	9101
				0.7	1.4	1044	8851
				1.0	2	1715	8752
Fassel	1500	15	1	0.5	1	1449	8758
				0.7	1.4	2255	8643
				1.0	2	2975	8428

Table 1 summarizes the values of residence time and maximum axial temperature for the conical and Fassel torches which were obtained using 2D axisymmetric simulations, as described elsewhere [2]. The residence times are measured from the tip of the injector tube to the optimum observation height where the maximum temperature is seen on the torch axis. It can be seen that the residence times are about 2 times shorter for the conical torch while using 40% and 50% less power and argon, respectively. The simulations also show about a 300 K higher LTE temperature for the conical torch which contributes to the shorter residence time. This improvement is believed to be leading to less diffusion of analyte species inside the plasma and hence the higher signal intensities for the conical torch.

3. Flow Pattern and Particle Trajectory

Due to its design, the Fassel torch is inherently prone to rotational and backward flow patterns which leads to a partial loss of sample and sensitivity. This fact has been shown by several research groups [11-14]. Our 3D simulations [11] also show that using low/no intermediate gas or wider injector tubes specially intensify these rotational patterns (Fig. 2-b). On the contrary, the sample particles introduced to the conical torch is seen to always follow a forward path (Fig. 2-a). In combination with the short residence time, the improved flow pattern can potentially lead to a higher sample throughput with minimum sample loss for the conical torch. This is particularly important for analysis of samples which are available only in small amounts such as cell analysis in biomedical applications or nanoparticles in various medical, biological, environmental, or industrial fields.

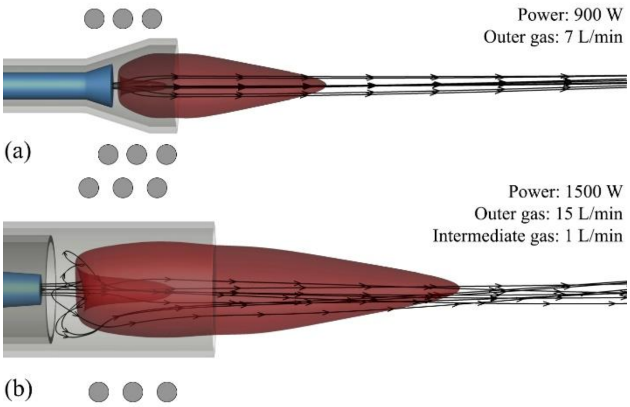


Fig. 2. 3D computer simulations of flow patterns inside the (a) conical and (b) Fassel torches.

4. Plasma Stability and Resistance to Extinguishing Factors

The outer gas velocity in the conical torch is more than 3 times higher than that of the Fassel torch at the same flow rate, which is a result of the conical design of this torch leading to 50 – 70% less gas consumption. In addition, the conical geometry is shown [2] to form a strong field of negative pressure inside the torch. This effect causes the plasma to be pulled in and lead to better plasma stability, faster ignition process, and higher tolerance against extinguishing factors such as introduction of organic solvents or ingression of air.

For example, Fig. 3 shows that the conical torch tolerates organic samples very well with only 900 W of power. Needless to say that using such a low power in the Fassel torch not only leads to poor analytical performance for organic samples but also leads to quenching of the plasma. Interestingly, Fig. 3 shows that the brightness of the blue color—due to emission from yttrium ions—inside the conical torch is higher at 900 W compared to the Fassel torch at 1500 W.

This means that the hotter plasma produced by the conical torch at a lower power is able to ionize and excite a higher percentage of yttrium atoms. For the Fassel torch, an orange plume can be observed at the back of the plasma which is a sign of excited soot particles getting into the rotational flows inside this torch.

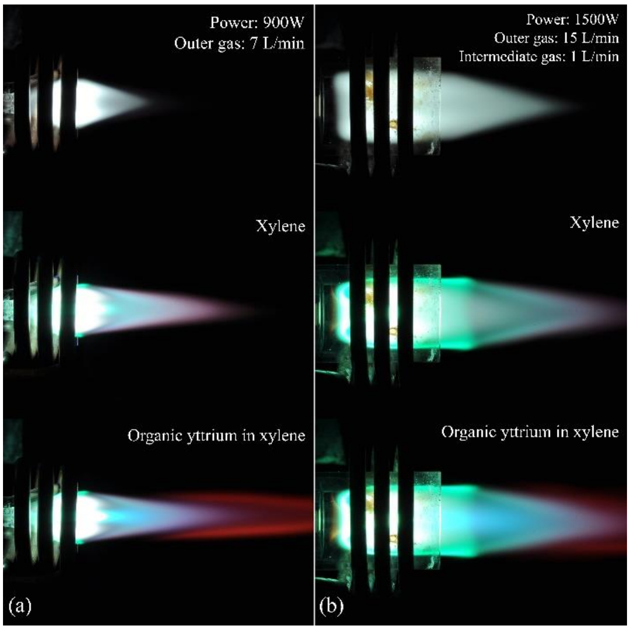


Fig. 3. Comparison of the (a) conical and (b) Fassel torches upon introduction of xylene and organic yttrium dissolved in xylene. The injector inner diameters are 1 mm and 1.2 mm for the conical and Fassel torches, respectively.

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