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A Review on Inductively Coupled Plasma Optical Emission Spectrometry (Icp-Oes) with a Special Emphasis on its Applications

Siva Sai Kiran B*,Raja S

GITAM Institute of Pharmacy, GITAM University, Visakhapatnam- Andhra Pradesh, India

***Corresponding author:** Siva Sai Kiran B, Department of Pharmacy, Gitam University - Rushikonda, Visakhapatnam, India, Tel: +91 9700572717; E-mail: sivasaikiran143@gmail.com*

ABSTRACT

Spectroscopy is one of the most widely used technique for estimation of compounds at atomic and molecular level by determining their energy states by studying the light absorbed or emitted when they change states. Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) has emerged as a powerful analytical technique in recent days. This instrument is employed for liquid samples which are atomised and further desolvated, vaporized, atomized, and excited and/or ionized by the plasma. This excited atoms and ions emit their characteristic radiation which is a wavelength adopted for interpretation of concentration information for the analyst. The ICP-OES can measure even trace concentrations of various elements with higher degree of sensitivity and precision even upto PPB level. The drug regulatory bodies are projecting a considerable position in the modern analytical laboratories for routine analysis. The present review highlights the various components of ICP-OES, the advantages of ICP over other analytical techniques for determine metals and a brief literature review on applications of ICP-OES in various fields such as pharmaceuticals, food, environmental, biological, metallurgical, geological and marine applications.

Key words: Spectroscopy, ICP-OES, applications, Metal Analysis.

INTRODUCTION

Inductively Coupled Plasma has been commercially available for over 40 years and is used to measure trace metals in a variety of sample matrixes in solution form. ICP can be performed using various techniques, two of which are inductively coupled plasma - optical emission spectroscopy (ICP-OES) and inductively coupled plasma - mass spectrometry (ICP-MS). This discussion will focus on ICP-OES. It has been 25 years since ICP-OES began to be widely used, and is now one of the most versatile methods of inorganic analysis. The inductively coupled plasma is an eddy (or ring-like) plasma, in which the volume filled by the ionized gas is comparable with a short circuited secondary turn of a transformer. In the plasma generating system an induction coil surrounds a quartz tube ~ 2.5 cm in diameter through which flows argon gas [1].

Sample solutions are introduced into the ICP as an aerosol that is carried into the centre of the plasma (superheated inert gas). The plasma de-solvates the aerosol into a solid, vaporizes the solid into a gas, and then dissociates the individual molecules into atoms. This high temperature source (plasma) excites the atoms and ions to emit light at particular wavelengths, which correspond to different elements in the sample solution. The intensity of the emission corresponds to the concentration of the element detected [2].

Materials and Methods

ICP-OES is one method of optical emission spectrometry. The sample solution is introduced into the system with high pressure which is produced by pumps into a nebulizer [3-5]. where the sample is converted into an aerosol. A spray chamber [6] is between nebulizer and torch which drains the excess droplets in aerosol through drain and allows the sample to pass into torch [7]. In the torch when plasma energy is given to an analysis sample from outside, the component elements (atoms) is excited. To generate plasma, first, argon gas is supplied to torch coil, and high frequency electric current is applied to the work coil at the tip of the torch tube. Using the electromagnetic field created in the torch tube by the high frequency current, argon gas is ionized and plasma is generated. This plasma has high electron density and temperature (10000K) and this energy is used in the excitation-emission of the sample. When the excited atoms return to low energy position, emission rays (spectrum rays) are released and the emission rays that correspond to the photon wavelength is collected by using various optics [8] and wavelength devices [9-11] are measured by using various detectors [12-16]. The element type is determined based on the position of the photon rays, and the content of each element is determined based on the ray's intensity. Signal processing units and computers are present to read the result by the analyst.

Table 1: What are the advantages of ICP over other analytical technique?

PARAMETER	OTHER TRACE METAL ANALYSIS INSTRUMENTS (AAS & GFAAS)	ICP-OES
Number of elements analyzed at once	Single	Simultaneous, sequential analysis of multiple elements possible
Linearity	range from 2 to 3 orders of magnitude	ranges from 4 to 6 orders of magnitude
Chemical Interference	High	Less
Sensitivity	Low	High sensitivity (low limit of detection for majority of elements is 10 ppb or lower)

Excitation Temperature for excitation of many elements.	air-acetylene flame measures at 2000 to 3000 K	excitation temperature of argon ICP is 5000 to 7000 K
Other	difficult to analyze elements such as Zr, Ta, rare earth, P and B.	Easily analyzes elements such as Zr, Ta, rare earth, P and B.
Note: AAS- atomic absorption spectrometer, GFAAS- graphite furnace atomic absorption spectrometer.		

INSTRUMENTATION [17]

Equipment for ICP-OES consists of a light source unit, a spectrophotometer, a detector and a data processing unit. There are several types of equipment based on differences in the Spectrophotometer and the detector. The most common type is shown in (Figure 1).

Sequential type

A spectrophotometer with a Czerny-Turner monochrometor, and a detector with a photomultiplier is most common for this type. With this equipment, programmed wavelength of the spectrophotometer is consecutively varied to measure multiple elements. This causes rather long measuring time, however, with its high resolution spectrophotometers, it is favorable for measurement of high-matrix samples.

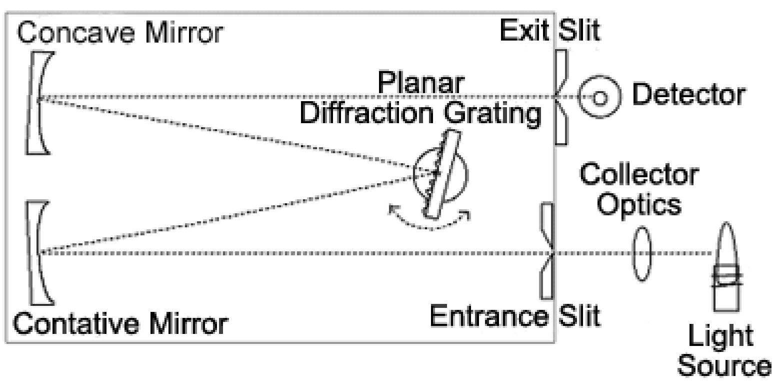

Figure 1: Sequential Type ICP-OES

Simultaneous Type

This type typically uses an echelle cross disperser in spectrophotometers and semi-conductor detector such as CCD for the detector. Echelle cross disperser disperses light of measurable wavelength range two-dimensionally by combining prism and echelle diffraction grating. Combination of echelle cross disperser and a CCD detector enables multi-element measurement at any wavelength. The most notable feature of this equipment is the high-speed measurement, providing information on all 72 measurable elements in measurements of 1 to 2 minutes normally.

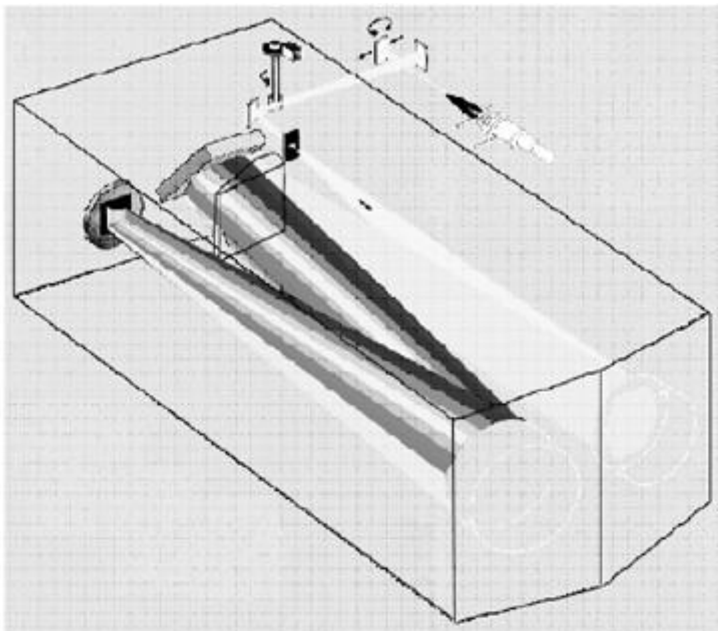

Figure 2: Simultaneous ICP-OES

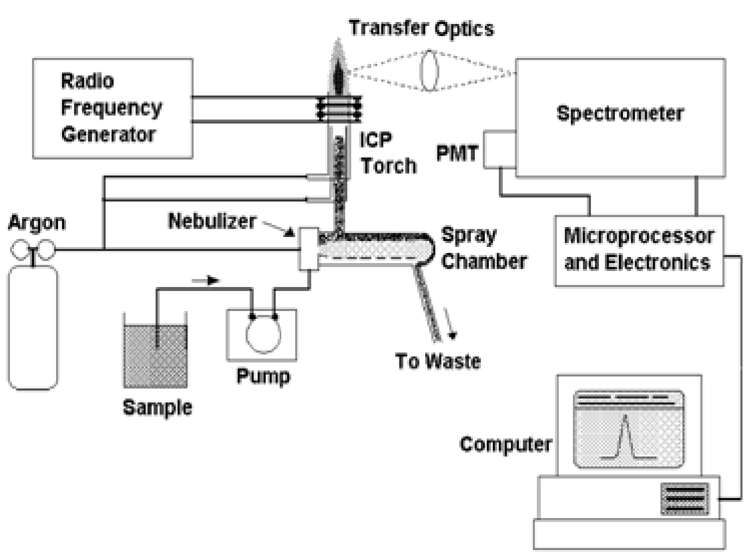

Figure 3: Block diagram of ICP-OES instrumentation

APPLICATIONS

Agricultural and Foods

- The ICP-OES technique has been applied to the analysis of a large variety of agricultural and food materials. Types of samples include soils, fertilizers, plant materials, feedstuffs, foods, animal tissues, and body fluids. Analysis of infant formula for Ca, Cu, Fe, Mg, Mn, P, K, Na and Zn;
- Determination of trace metals in beer and wine.

Biological and Clinical

The use of surgical equipment, such as scalpels, needles, scissors, and forceps, often contaminates the sample with trace quantities of the very elements being determined in the sample.

- Determinations of Cr, Ni and Cu in urine.
- Determination of Al in blood.
- Determination of Cu in brain tissue.
- Determination of Se in liver.
- Determination of Ni in breast milk.
- Determination of B, P and S in bone.
- Determination of trace elements in oyster and tuna.

Geological

- Determination of major, minor and trace compositions of various rocks, soils, sediments, and related materials.
- The major use of ICP-OES in this field is mainly used for prospecting purposes.
- The technique is also used for applications such as determining origins of rock formations and for marine geochemistry.
- Determination of U in ore grade material.
- Analysis of river sediments for several metals
- Analysis of carbonate drill cores for major, minor and trace elements.
- Determination of rare earth elements in rock formations.
- Analysis of plankton for several elements.

Environmental and Waters

- Analyses of sewage sludge, domestic and industrial refuge, coal and coal fly ash, and dust and other airborne particulates.
- Various water quality analyses as required by the U.S. Environmental Protection Agency.
- Determination of Fe, Cd, Cu, Mo, Ni, V, and Zn in seawater.
- Determination of phosphorus in municipal wastewater.
- Determination of heavy metals in inner-city dust samples.
- Trace metal analysis of coal fly ash.

Metals

- Determination of toxic, trace and major constituents in coal and slags.
- Analysis of low alloy steels for As, B, Bi, Ce, La, P, Sn and Ta; high-precision determination of Si in steels;
- Determination of contaminants in high-purity Al.
- Analysis of superconducting materials for trace contaminants.

Organics

- Analysis of organic solutions by ICP-OES is important not only for analyzing organic-based materials such as petroleum products but also for a wide variety of
  Other applications.
- The analysis of used lubricating oils for trace metal content is one of the more popular applications for organics analysis by ICP-OES. Some other applications include analysis of solvent-extracted geological materials for trace elemental composition.
- Determination of lead in gasoline;
- Determination of Cu, Fe, Ni, P, Si and V in cooking
- Analysis of organophosphates for trace contaminants.
- Determination of major and trace elements in antifreeze.

Pharmaceuticals

In recent decades united state pharmacopeia (USP) has made the determination of limits for heavy metals in pharmaceuticals by using ICP-OES as mandatory. The excess will of heavy metals in pharmaceuticals will detoriate the condition of the patient further.

Table 2: BRIEF LITERATURE REVIEW ON APPLICATIONS OF ICP-OES

S.No	Author	Sample	Metals Detected	Reference
1	**Mohammed M Rahman *et al.*, 2012.**	CuO-TiO_2 nanosheets	Iron (III)	[18]
2	**Akpinar- Bayizit .A *et al.*, 2010.**	35 commercial vinegar samples	*Major Elements* -Na, K, Ca, Mg and P. *Minor Elements* -Fe, Mn, Sn, Cu, Ni, Zn, Pb and Cd.	[19]
3	**Júlio C. J. Silva *et al.*, 2003.**	2 mg / L of Mg in 1% v v/ HNO_3 or in 10% v/v CFA-C(coal fry ash –c) media.	Magnesium	[20]
4	**Nikolaya Velitchkova *et al.,2013.***	Environmental Samples (Soil & Drinking Water)	Zn, Cd, Sb, Cu, Mn, Pb, Sn, Cr, U, and Ba in the presence of a complex matrix, containing Al, Ca, Fe, Mg, and Ti.	[21]
5	**AL-rajhi MA 2014.**	13 types of potato chips around the city of Riyadh	Cd, Cr,Cu, Fe, Mg, Mn, Ni, Pb, Zn, As, Se and Al	[22]
6	**Y. Yamini *et al.*, 2010.**	water samples	Mn, Cr, Co and Cu	[23]
7	**K. Uysal *et al.*, 2008.**	L. mormyrus, L. aurata, C. labrasus, M. cephalus, S. aurata and L. Ramada fish species in theWestern Mediterranean Coast of Turkey	Cu, Zn, Mn, Fe, Mg, Ni, Cr, Co and B	[24]
8	**V. S. Shrivastava *et al.*, 2011.**	Rahu, Tilapia and Catfish from Yamuna river.	Al, B, Ba, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sb, Sn, Si, P and Zn .	[25]
9	**Vallapragada VV *et al.*, 2011.**	Eliphos Tablets	Calcium and Phosphorous	[26]
10	**Thompson M *et al.*, 1978.**	Gaseous Hydrides of respective elements.	Arsenic, Antimony, Bismuth, Selenium and Tellurium.	[27]

11	**George F Larson Larson *et al.*, 1975.**	Investigations of the extent to which certain interelement or interference effects occur in an inductively-coupled plasma are reported.	Sodium	[28]
12	**Hasan Mohammadi Aghamirlou *et al.*, 2015.**	25 samples of multi floral honey were collected from individual beekeepers in four regions	As ,Cd, Cr, Pb, Ni, Zn, Cu.	[29]
13	**Miranda C. E. Lomer *et al.*, 2000.**	100 Food Samples from 42 manufacturers.	Titanium Dioxide (TiO_2)	[30]
14	**Beone GM *et al.*, 2000 .**	aliquot by aqua regia in soils and sediments	Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn.	[31]
15	**M. Rezaee *et al.*, 2010.**	Water Samples	Aluminium	[32]
16	**C. Huang *et al.*, 2007.**	Lake water, well water and pond water.	inorganic arsenic and antimony	[33]
17	**S.L. Ferreira *et al.*, 2001.**	Surface Sea Water in Salvador City, Brazil	vanadium and copper	[34]
18	**M. Faraji *et al.*, 2010.**	environmental water samples	Cd, Co, Cr, Ni, Pb and Zn	[35]
19	**A.M.Gunn *et al.*, 1977.**	Milk Powders	Phosphorous	[36]

CONCLUSION

There has been increasing interest in the determination of trace elements and heavy metals. Many methods such as atomic absorption spectrometry, inductively coupled plasma optical emission spectrometry (ICP OES) and inductively coupled plasma mass spectrometry (ICP MS) have been applied successfully. Among these techniques, ICP OES is now commonly used, and offers many advantages such as simple operation, a rapid analysis time, good detection limits, and a wide analytical dynamic range.

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