

[54] PULSED ULTRASONIC NEBULIZATION SYSTEM AND METHOD FOR FLAME SPECTROSCOPY

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 [51] Int. Cl. **B05b 17/06, G01n 21/56**
 [58] Field of Search **239/4, 8, 9, 13, 71, 74, 239/102, 128, 136-138, 338; 356/36, 85-87, 356/187; 431/12; 55/249; 23/253 PC**

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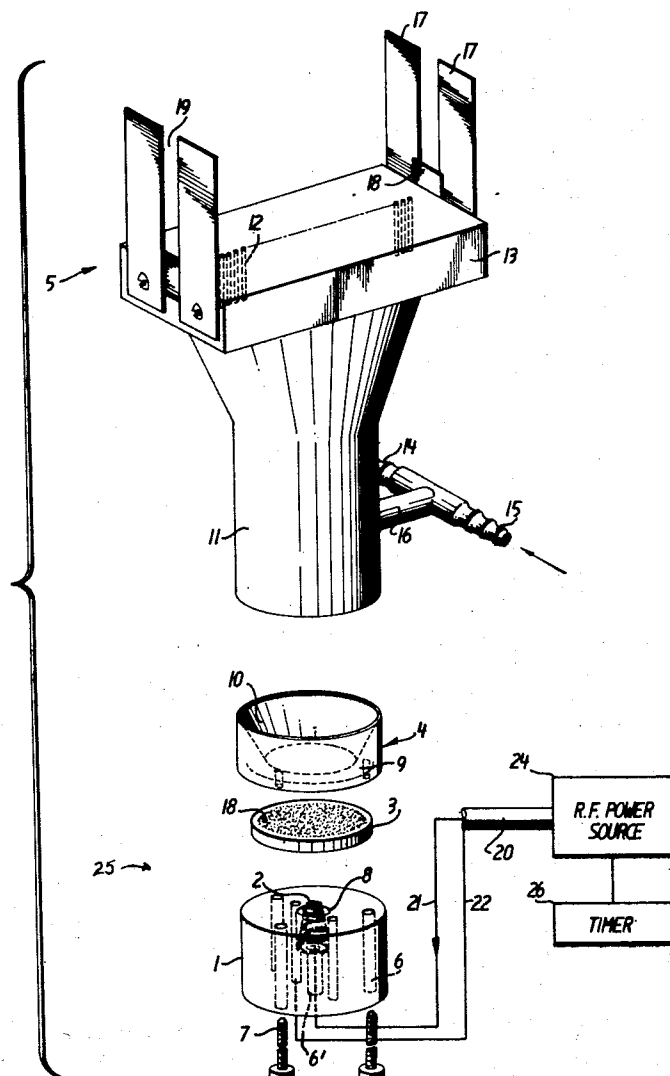
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[57] ABSTRACT

A system and method for nebulizing relatively small liquid samples for use in flame spectroscopic analysis. In a preferred embodiment, a 25 to 200 μ l liquid sample is provided in a sample cup adjacent a glass coated piezoelectric transducer for use in an atomic absorption spectrometer. The transducer is energized by a radio frequency power source which, in turn, is switched on for a preselected pulse or nebulization time. The sample volume and pulse time for a particular burner configuration are chosen to achieve an aerosol density for optimum absorbance characteristics.

15 Claims, 6 Drawing Figures



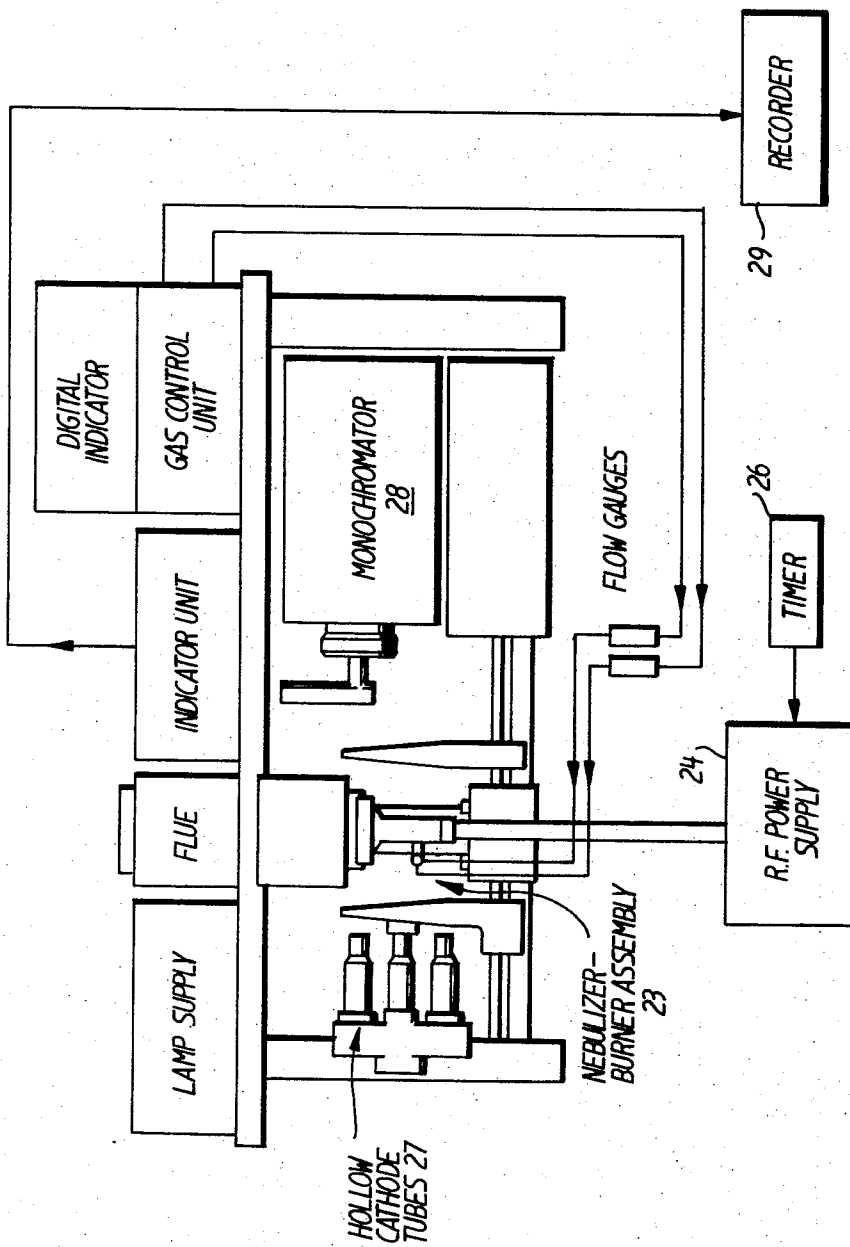
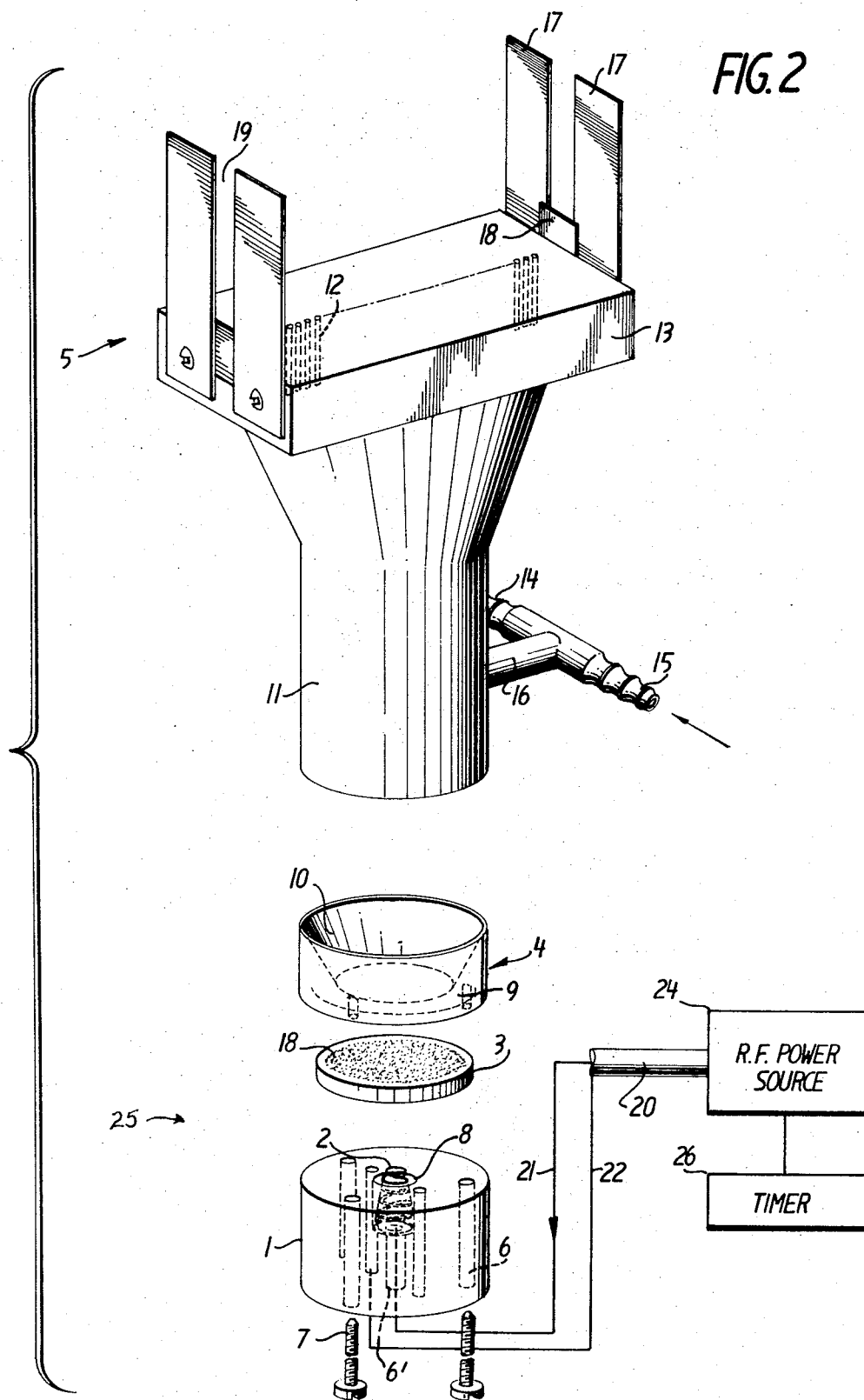


FIG. 1

FIG. 2



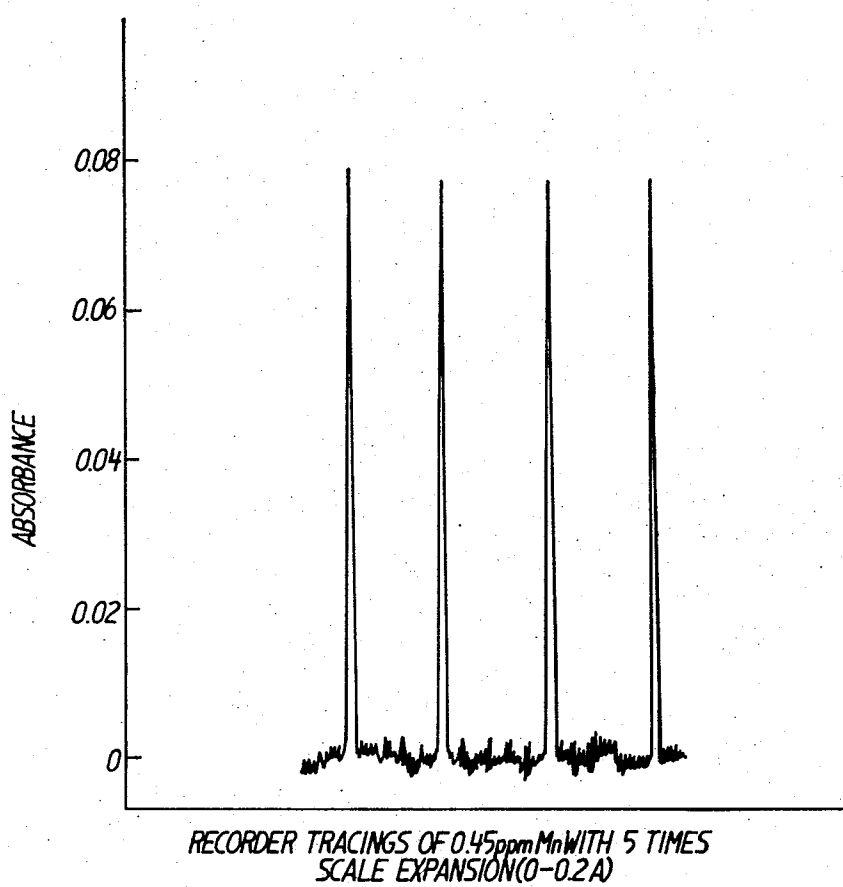


FIG. 3

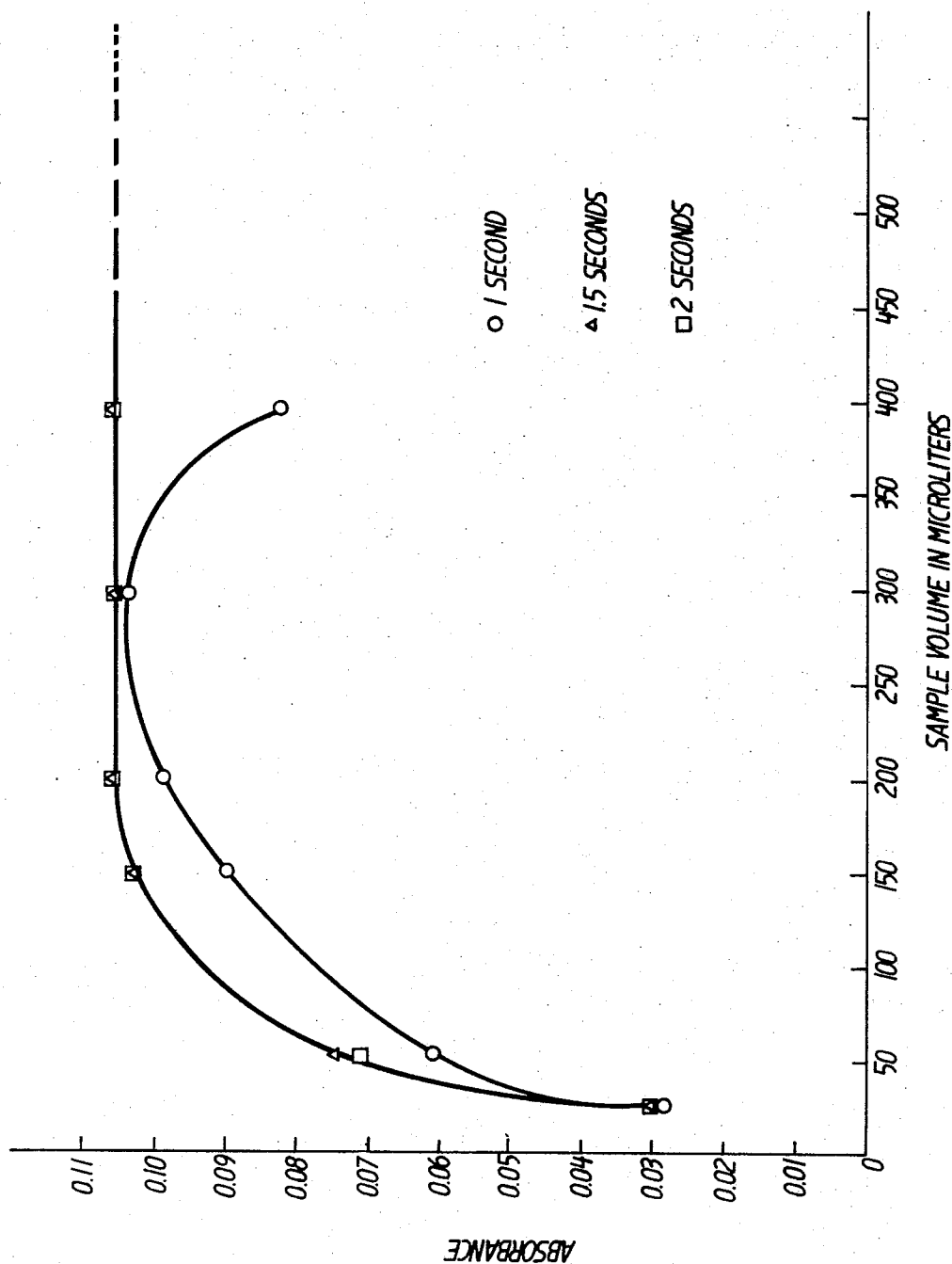


FIG. 4

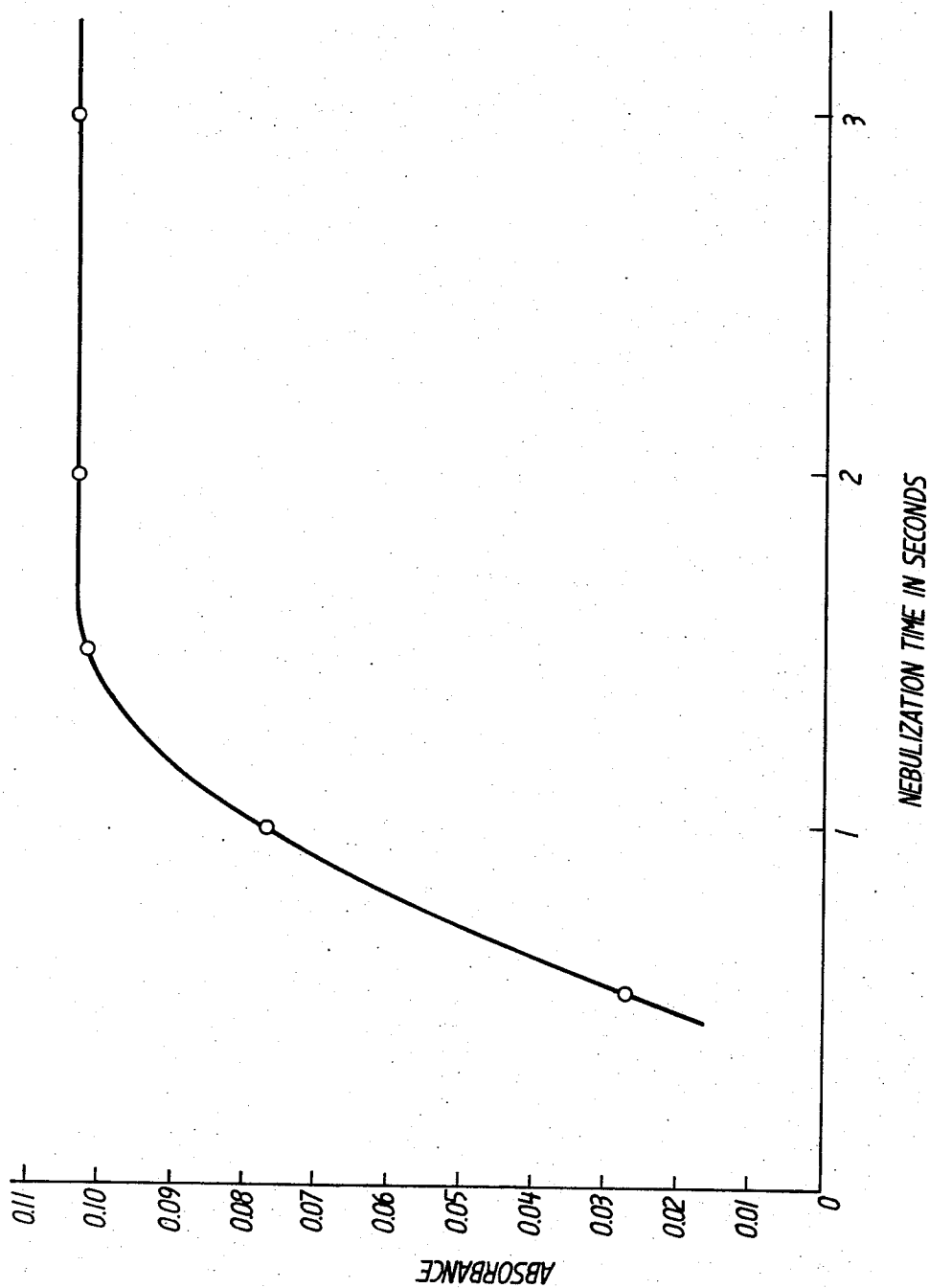


FIG. 5

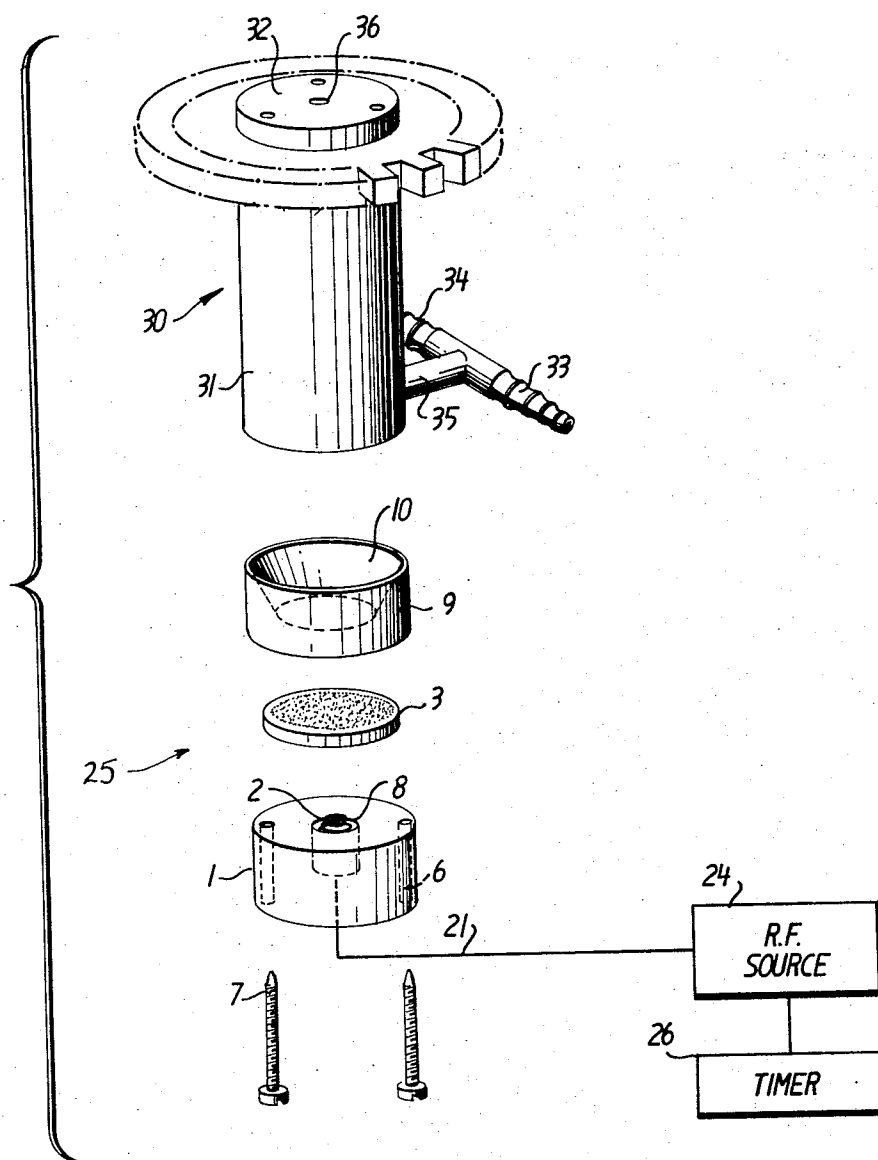


FIG. 6

PULSED ULTRASONIC NEBULIZATION SYSTEM AND METHOD FOR FLAME SPECTROSCOPY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved ultrasonic nebulization system and method and, more particularly, to a method and apparatus for effectively nebulizing a relatively small (25 to 200 μ l) liquid sample for use in flame analytical spectrometers, including atomic absorption, emission and fluorescent spectrometers.

2. Description of the Prior Art

Flame spectroscopic techniques, such as atomic emission, fluorescence and absorption spectroscopy, are all well known in the art as powerful tools for the analysis of the presence of various elements in a substance under test. For example, in atomic absorption spectroscopy radiation from a source such as a hollow cathode lamp is passed through an atomic vapor of the sample under test. The degree of absorption of the characteristic radiation by the atomic vapor is an indication of the presence of atoms having the same characteristic lines as the source. The free atoms in the atomic vapor are made available by dissociation of the molecules of the sample by a chemical combustion flame in a burner.

It is generally desirable to nebulize or atomize the liquid sample of the substance under test and to sweep the resulting fog into the reaction zone of the flame using a gas stream. As the energy is transferred to or absorbed by the individual droplets comprising the fog, some of the more volatile components are evaporated leaving a solid particle. Absorption of additional energy by the solid particle results in the particle reaching the boiling or sublimation point upon which it then becomes a gas. Further absorption of energy by the molecules produces chemical bond splitting resulting in free atoms in the ground or unexcited state which are capable of absorbing electromagnetic radiation of a resonant frequency. It is this fog or atomic vapor of ground state free atoms which produces the absorption necessary to the atomic absorption process. For emission spectroscopy, additional energy must be imparted to the free atoms to raise them to an excited state necessary to yield emission spectra.

In recent years, it has become of increasing importance to be able to analyze samples of very small volume such as are frequently used in clinical and environmental analysis. It is of additional importance to be able to carefully control the droplet sizes generated by the nebulizer in order to reduce light scattering problems and certain types of interferences.

Today, however, most commercially available spectrometers utilize indirect pneumatic nebulizers for the introduction of samples into a flame burner. These pneumatic spray systems generate a wide range of droplet sizes of the liquid sample. Consequently, such burner systems are generally modified to include a system of baffles to remove the larger size droplets before the aerosol reaches the flame of the burner. However, a major problem with conventional pneumatic nebulizers continues to be their inefficient use of the samples introduced, inasmuch as only 3 to 12 per cent of the solution aerosol is actually introduced into the flame.

High frequency ultrasonic nebulization is a known technique for generating an aerosol which is composed of only small droplets and which can be efficiently in-

troduced into the flame of the burner with only a negligible loss of sample. A prior art ultrasonic nebulizing system for use in atomic absorption spectrometry is described in a paper by Denton and Malmstadt in *Analytical Chemistry*, Volume 44, February, 1972, pages 241, et seq. The system described in the foregoing paper utilizes what is known in the art as the "batch technique" in which 20 - 50 ml of sample solution is introduced into the nebulizer and a continuous radio frequency source is utilized to energize an ultrasonic transducer for nebulizing the sample. After 15 - 30 seconds of continuous energization, the aerosol concentration in the nebulization chamber reaches an equilibrium to achieve a constant flow into the burner, after which a readout is obtained by conventional instrumentation. Although the foregoing ultrasonic nebulization system provided a great improvement in sensitivity over conventional prior art pneumatic nebulizers, a problem still exists in that, as pointed out above, sample solution sizes of 20 - 50 ml are required. Naturally, this sample size requirement is a severe limitation in situations where only small samples are available, and/or where analysis of a large number of elements from a given sample is required. In prior art nebulizers, dilution of the available small sample to yield the required volume necessary often leads to prohibitively low sensitivities necessary for accurate analysis.

A number of flame-related "sampling boat" and flameless techniques have been investigated and, while somewhat satisfactory, give rise to various interference problems which limit their use with varying sample sizes normally required. Moreover, the reduction or elimination of these interference problems generally requires a complicated optical system and temperature programming which far outweigh their limited utility.

Therefore, a need continues to exist for a practical and sensitive nebulization system which combines the desirable characteristics of flame atomization with an ultrasonic nebulizer system capable of reproducibly nebulizing small volumes of solutions.

SUMMARY OF THE INVENTION

Accordingly, one object of the present invention is to provide a new and improved ultrasonic nebulization system which reproducibly nebulizes small volumes of liquid sample solutions for use in flame spectroscopic analysis.

Another object of the present invention is to provide a new and improved ultrasonic nebulization system which produces an aerosol containing uniform small droplets from small volumes of liquid samples and which can be adapted for use in atomic emission, absorption and fluorescence spectrometers.

A further object of the present invention is to provide a method of producing an aerosol from a small volume of liquid sample for use in flame spectroscopic analysis.

Yet another object of the present invention is to provide an ultrasonic nebulization system and method for flame spectrometry in which heretofore impractical small volumes of liquid samples can be effectively and reproducibly nebulized for analysis.

The foregoing and other objects are attained in accordance with one aspect of the present invention through the provision of a pulsed ultrasonic nebulizer system for flame spectroscopy, which includes means for receiving a liquid sample to be analyzed, means for generating a pulsed RF signal and transducer means re-

sponsive to the pulsed RF signal for nebulizing the liquid sample into an aerosol spray. In one embodiment, a 25 μ l to 200 μ l liquid sample is provided in a solution cup adjacent a glass coated piezoelectric transducer. A radio frequency signal of 3 MHz. is utilized to energize the transducer. A precision timer is provided for switching on the power source for a preselected time period corresponding to the desired nebulization time for the liquid sample. The pulse time of the timer is most efficiently chosen to nebulize the entire sample. However, reproducibility can be achieved with small variations in sample size by carefully controlling the pulse time of the timer.

BRIEF DESCRIPTION OF THE DRAWINGS

Various objects, features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood from the following detailed description of the present invention when considered in connection with the accompanying drawings, in which:

FIG. 1 is a schematic diagram illustrating the various components of a conventional atomic absorption spectrometer incorporating a preferred embodiment of the pulsed ultrasonic nebulization system of the present invention;

FIG. 2 is a partially exploded perspective view of a preferred embodiment of the pulsed ultrasonic nebulizer of the present invention combined with an integral burner assembly for use in the atomic absorption spectrometer of FIG. 1;

FIG. 3 shows recorder tracings of an atomic absorption spectrum of a solution containing 0.45 ppm manganese obtained from the system shown in FIG. 1 for illustrating the reproducibility of the system of the present invention;

FIG. 4 is a graph of absorbance versus sample volume for varying pulse times for illustrating the sensitivity available with the system of the present invention for a solution containing 0.9 ppm manganese;

FIG. 5 is a graph of absorbance versus nebulization pulse time showing the sensitivity obtainable with the system of the present invention for 200 μ l samples of a solution containing 0.9 ppm manganese; and

FIG. 6 is a partially exploded, perspective view of a preferred embodiment of the pulsed ultrasonic nebulization system of the present invention in combination with a burner suitable for use in an atomic emission or fluorescent spectrometer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to FIG. 1 thereof, a conventional atomic absorption spectrometer system is illustrated in combination with the pulsed ultrasonic nebulization system of the present invention. For brevity and clarity, most of the following description of the principles of operation of the system of the present invention will be made in connection with its use in an atomic absorption spectrometer such as that depicted in FIG. 1, although it will be readily apparent to those skilled in the art that the pulsed ultrasonic nebulizer of the present invention can also be adapted for use in atomic emission and fluorescent spectrometers.

The atomic absorption spectrometer of FIG. 1 is seen to consist essentially of a source of characteristic radiation in the form of hollow cathode tubes 27 passing light through the atomic vapor provided by the nebulizer-burner assembly 23. The absorption of the characteristic radiation by the atomic vapor can be measured by a conventional monochromator 28 and recorded by various apparatus for subsequent analysis such as a strip chart recorder 29. The pulsed ultrasonic nebulizer of the present invention is in this embodiment incorporated into the base of nebulizer-burner assembly 23 and is powered by a radio frequency power supply 24 which is, in turn, controlled by a precision timer 26 in a manner that will be described in more detail hereinafter. The operation and interconnection of the remaining components of the atomic absorption spectrometer shown in FIG. 1 is well within the knowledge of a person of ordinary skill in the art, and thus, need not be given in detail here. For a more detailed description of possible component selection and operation parameters of the system of FIG. 1, reference is made to an article by Korte, Moyers and Denton appearing in Volume 45 of *Analytical Chemistry*, March, 1973, pages 530 - 534, entitled "Investigations into the Use of a Pulse Ultrasonic Nebulizer-Burner System for Atomic Absorption Spectrometry."

Referring now to FIG. 2, a preferred embodiment of nebulizer-burner assembly 23 of FIG. 1 which incorporates the teachings of the present invention is seen to include a burner portion 5 and an ultrasonic nebulizer portion 25. For clarity and ease of explanation, ultrasonic nebulizer assembly 25 is illustrated in a partially exploded view, although it is understood that in final assembly the various components are press fitted into the base of burner 5.

Ultrasonic nebulizer assembly 25 essentially comprises a solution cup 4, an ultrasonic transducer 3, and a base portion 1, all of substantially circular cross section and adapted to form an unitary sandwich-like assembly. The base 1 contains a centrally positioned aperture 8 which accommodates a spring contact 2. Several channels 6 are formed in base 1 for accommodating screws 7 which secure base 1 to the bottom of solution cup 4 by means of the apertures 9. Another channel 6' is provided in base 1 directly beneath aperture 8 which accommodates a lead 21 of a cable 20 which conducts a radio frequency (RF) signal to the spring contact 2 from a conventional RF power source 24. The RF power source 24 is activated and deactivated for a predetermined time period, as will be described more fully hereinafter, by a control device such as a timer 26. Grounding is accomplished by securing a ground lead 22 to one of the screws 7.

Solution cup 4 has a tapered aperture 10 formed therein for receiving the liquid sample to be analyzed and to allow direct contact of the liquid sample with the transducer 3. Transducer 3 may be comprised of any suitable ultrasonic transduction material. For example, transducer 3 may be constructed from a piezoelectric material such as barium titanate or lead zirconate. The upper surface 18 of transducer 3 is preferably coated with a layer of glass in order to provide surface 18, which is exposed to the analyte solution, with the required inert chemical properties. One example of a suitable transducer for use in the ultrasonic nebulization system of the present invention is a C 600 barium titanate transducer fabricated with a coaxial electrode

geometry. Solution cup 4 and base 1 may be formed from any suitable inert material, such as polytetrafluoroethylene. Spring contact 2 may be formed for example, of beryllium bronze, or other equivalent resilient and conductive material.

Base 1 is firmly attached to solution cup 4 by means of screws 7, transducer 3 being sandwiched therebetween in firm contact with spring contact 2. When assembled, the ultrasonic nebulization apparatus 25 is press fitted into the base of burner 5. Transducer 3, which is activated by the signal from RF power source 24, causes a fine aerosol spray of the liquid sample which is in contact with transducer 3 in the bottom of solution cup 4 to be generated. The present invention is, in one aspect, concerned with the volume of liquid sample necessary for analysis. In another aspect, the present invention deals with the mode of excitation of transducer 3. The foregoing and other aspects will be treated in more detail hereinafter.

Still with reference to FIG. 2, the burner portion 5 of the nebulizer-burner assembly 23 is seen to include a flue 11 which widens just beneath a plurality of burner ports 12 positioned linearly and longitudinally across a burner block 13. Flue 11 is provided with a pair of entry ports 14 and 15 which emit fuel and oxidizer, respectively, through a stem 16 into the flue. The fuel-oxidizer mixture which is admitted into flue 11 combines with the fine droplets of the liquid sample aerosol which is to be analyzed, and the aerosol-fuel-oxidizer mixture then passes upwardly through ports 12 where the mixture is burned.

Two important considerations limit the size of flue 11. If the interior dimensions of the flue are too small, the droplets of the aerosol created by ultrasonic nebulizer 25 will coalesce resulting in the formation of larger sized droplets which adhere to the inner surfaces of the flue. This will result in a decrease in sensitivity of the spectrometer and will adversely affect the quantitative reproducibility of the output data. On the other hand, if the interior dimensions are too large, the aerosol will be diluted with the fuel-oxidizer mixture beyond the point where accurate and reproducible measurements can be made.

The top portion of the burner 5 includes one pair of spaced vertical flanges 17 disposed on each side of burner block 13. Vertical slits 19 are positioned between each pair of flanges 17 to permit radiation from the hollow cathode tube to pass therethrough. The width of vertical slits 19 can be, for example, about 4 mm. Horizontal cut-offs 18 are fixedly secured to the bottom of vertical slits 19 on the opposing sides of burner block 13 and function to prevent radiation from traveling through the central flame cones when the lower portions of the flame are being used. This is very important since the fuel and oxidizer are not being burned in the flame cones, and the aerosol present in the cones would cause light scattering. The vertical dimensions of the horizontal cut-offs are preferably the same height as the flame cones and can be, for example, 3 mm. In an experimental burner constructed according to the foregoing principles, the path length (distance between oppositely disposed flanges) was 5 cm and comprised 33 burner ports each being 0.813 mm in diameter and spaced at 1.52 mm intervals. The burner block 13 had a thickness of 1.27 cm.

In operation, the proper frequency of excitation for the transducer is initially determined by operating the

transducer outside of the burner. Maximum aerosol generation is provided by adjusting the frequency of the transducer without generating large "splash" droplets. Production of these large droplets must be avoided to prevent clogging of the burner ports 12 as well as to insure reproducible aerosol generation. Once the frequency for the transducer is determined, no further adjustments are necessary. For the exemplary procedures conducted to verify the principles of the present invention, utilizing the aforescribed barium titanate transducer, the overtone frequency of 3 MHz. was discovered to be optimum for maximum generation of uniformly small aerosol droplets. RF power source 24 was therefore selected to deliver up to 200 watts of power at the operating frequency of 3 MHz.

After the optimum excitation frequency of the transducer is determined, a 200 μ l (0.2 ml) or smaller liquid sample of the substance to be analyzed is injected into the solution cup 4 and onto the upper surface 18 of transducer 3. The ultrasonic nebulizer assembly 25 is then inserted into the bottom opening of the flue 11 of the burner 5. Alternatively, it is within the scope of the present invention to fit ultrasonic nebulizer 25 onto the flue 11 of the burner 5 without a solution cup, and to inject a small sample directly onto the surface of transducer 3 through an entry port or the like.

The greatly reduced sample volume which may be analyzed in the system of the present invention when compared with those sample volumes required for prior art pneumatic and ultrasonic nebulizers in turn requires the utilization of a modified excitation technique to prevent the transducer from burning out after the small volume of solution has been completely nebulized. Accordingly, in contrast to prior art systems which supply a continuous source of RF power to the transducer, the present invention provides a control device, such as a precision timer 26, for accurately activating and deactivating the RF power source 24 for a preselected time interval corresponding to the desired nebulization time of the particular volume of liquid sample being analyzed. Timer 26, which for example may comprise a monostable multi-vibrator, may be provided with a precision potentiometer to allow the selection of a range of time constants, thereby permitting a choice in nebulization times from, for example, 0.4 to 8 seconds.

Accordingly, after the ultrasonic nebulizer 25 containing the small volume sample is in position within flue 11 of burner 5, the time constant for timer 26 is set for the desired nebulization time which, for example, may be 1.5 seconds. Timer 26 is then activated which, in turn, activates source 24 and transducer 3 for a period of 1.5 seconds. The aerosol generated by the vibrating transducer is swept up into flue 11 of burner 5 where it mixes with the fuel-oxidizer mixture entering port 16. The resulting mixture is swept through burner ports 12 whereupon it is burned while the radiation is passed through it. The output from the spectrometer recorder is typically a pronounced spike indicative of the wave length of the metal present in the vapor. The peak height of the spike is a measure of the absorbance of the particular element under test and is also proportional to the sensitivity of the particular nebulization technique.

Experimental studies with the pulsed ultrasonic nebulization system of the present invention indicate far superior sensitivities are obtainable when compared with prior art pneumatic nebulization systems in atomic

absorption spectrometers. See, for example, the above-cited article by Korte et al., which describes an average improvement in sensitivity exceeding fourfold obtained with the system of the present invention when compared with the sensitivity observed with a conventional pneumatic nebulizer.

Furthermore, the volume of sample solution required by prior art pneumatic and ultrasonic nebulizers far exceeds that necessary with the system of the present invention. This becomes critical in situations where only small samples are available and/or where analysis of a large number of elements is desired, such as for example, in the analysis of atmospheric particulate matter. For example, with conventional prior art pneumatic nebulizer-burner systems, a minimum of approximately 0.75 ml is needed to perform an accurate reproducible determination. Furthermore, convenience and the attainment of a steady state by the signal often necessitate the use of up to 2 ml of sample per element. Prior art ultrasonic nebulizers that utilize the above-described "batch technique" also require unusually large sample volumes — 30 to 50 ml. As pointed out above, in order to test for a large number of elements in a particular sample in prior art nebulizers with large sample volume requirements, dilution of the sample is often necessary, frequently leading to prohibitively low sensitivities necessary for accurate analysis. In contrast, the pulsed ultrasonic nebulization system of the present invention enables convenient and reproducible analysis with as little as 25 μ l of sample, thus eliminating or reducing dilution requirements. The technique of the present invention is much more versatile than prior art techniques in performing multi-element analysis on single small samples, in that if a particular element is apt to be present in very low concentrations, a 200 μ l sample can be used for maximum sensitivity. On the other hand, for elements expected to be present in substantial amounts in the small sample, a 25 μ l sample can be used, thus allowing much more efficient use of the total, yet small, sample.

FIG. 3 represents typical reproducibility data (recorder tracings) obtained from an analysis of a 200 μ l sample solution containing 0.45 ppm manganese in the atomic absorption spectrometer of FIG. 1 utilizing the pulsed nebulization system of the present invention. The average per cent difference from the mean for a typical set of data is less than 2 percent, while the per cent difference between the largest and smallest response for a particular sample is typically better than 6 percent. When a pure solvent is analyzed, no signal is observed even when the radiation from the hollow cathode passes very low in the flame, showing the rapid desolvation of the small droplets produced by the pulsed ultrasonic nebulizer of the present invention.

The affect of the size of the sample volume and the nebulization or pulse time on the analysis of manganese samples are shown in FIGS. 4 and 5 respectively. FIG. 4 shows that in an analysis of a 0.9 ppm manganese solution, maximum sensitivity is reached at a sample volume of about 200 μ l which is the point at which the entire transducer crystal is just covered with solution. As the volume of the sample is further increased, more and more sample remains in the cup indicating that the pulse time is too short to nebulize the entire sample. However, at longer pulse times, although more sample is nebulized for the larger volumes, sensitivity does not significantly increase. Thus, at a pulse time of 1.5 sec-

onds and with a sample volume of 200 μ l, optimum aerosol density is achieved for the burner configuration depicted in FIG. 2. When volumes of sample larger than 350 to 400 μ l are used, large splash drops begin to form which can clog the burner ports.

FIG. 5 shows a graph of pulse or nebulization time versus absorbance for a 200 μ l sample of 0.9 ppm manganese. Within 1.5 seconds, essentially 100 percent of the sample is nebulized, with larger pulse times having no further effect. At shorter pulse times, an optimum aerosol density is not obtained and the sensitivity decreases. FIGS. 4 and 5 demonstrate that optimum absorbance for a given concentration with the system of the present invention is obtained with 200 μ l sample volumes and a pulse time of 1.5 seconds.

For a given weight of an element, absolute sensitivity decreases with sample size. However, with the system of the present invention, as the sample size is decreased, the absorbance or sensitivity decreases but not to the same extent or rate as the sample size. For example, when decreasing sample size for manganese from 200 μ l to 50 μ l, the sensitivity drops from 0.025 ppm to 0.06 ppm. Thus, while sensitivity was decreased by a factor of 2, sample size was decreased by a factor of 4. The reproducibility of the determinations when decreasing sample size is also somewhat effected; however, the per cent deviation for any number of readings is generally less than 10 percent and is typically about 6 to 8 percent. The foregoing data illustrates that the system of the present invention offers a substantial improvement in reducing the volume of sample normally required for flame spectrometric techniques.

The loss in reproducibility at smaller sample volumes can be attributed primarily to the manipulation of the very small volumes. Also, a piezoelectric crystal can produce nodal points, depending upon the exact frequency applied to the crystal. With very small sample volumes, liquid which falls on the nodal areas of the crystals are not efficiently nebulized and erratic data can result. These nodal points may be eliminated either by slightly changing the frequency of the radio frequency power generator or by simply not applying sample to the effected areas of the crystal. The use of either procedure eliminates the problem, thereby yielding reproducible data.

In conducting a series of analyses with different kinds of solution samples, cross-contamination from one sample to another was not observed. Moreover, sample solutions have not been observed to collect on the interior surfaces of the burner assembly. This can be attributed to the geometry of the burner and to the reduced likelihood of impacting the very small droplets produced by the ultrasonic nebulization at 3 MHz. at the surface of the burner. The droplets possess so little inertia that they are easily swept from stationary boundary layers, which can exist adjacent the burner walls, by the flowing aerosol-fuel-oxidizer gas stream.

Referring now to FIG. 6, the pulsed ultrasonic nebulization system 25 of the present invention is shown in combination with a burner 30 especially suitable for use in atomic emission or fluorescent spectrometers. The burner 30 comprises a flue 31 on top of which is positioned a burner head 32 which contains a plurality of centrally positioned burner ports 36. A fuel-oxidizer mixture is admitted through entry ports 33 and 34, respectively, which pass into flue 31 through a stem 35 where the gas mixture mixes with the pulsed aerosol

liquid sample delivered by pulsed ultrasonic nebulizer 25 in substantially the same manner as set forth with respect to the burner-nebulizer apparatus depicted in FIG. 2. In a sample nebulizer-burner assembly constructed according to the embodiment depicted in FIG. 6, burner ports 36 were 25 in number, each having a diameter of 0.50 mm. A premixed O_2-H_2 flame was utilized, the oxygen and hydrogen having flow rates of 3.2 l/min. and 9.0 l/min. respectively. Other fuel-oxidizer mixtures suitable for use in emission or fluorescent spectrometry include an oxygen-acetylene mixture, and nitrous oxide-acetylene. A comparison study of sensitivities obtainable from the pulsed ultrasonic nebulizer-burner system of the present invention depicted in FIG. 6 and a conventional prior art ultrasonic nebulizer utilizing the "batch technique" yielded comparable sensitivities although the sample volume required for the system of the present invention was only 200 μ l while the sample volume required for the "batch technique" ultrasonic nebulizer was 50 ml.

It is apparent that the present invention provides a high power pulsed ultrasonic nebulization system and method which is an extremely efficient and reproducible system for converting extremely small sample volumes into aerosol and delivering virtually the entire sample into the flame. The pulse time can be most efficiently chosen to nebulize the entire sample volume to yield the best response per unit volume of sample. A more important factor, however, with respect to reproducibility is the ability to carefully control the pulse time of the applied radio frequency signal to the transducer.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. For example, direct transducer to sample contact is not required; the acoustical energy can be coupled through cooling means such as a Mylar membrane and water to energize the sample volume placed on the membrane. Also, the distance from the nebulizer to the burner head will vary from burner to burner, and it is understood that the nebulizer and burner need not necessarily be an integral assembly, although the foregoing has proved to yield an extremely efficient and sensitive system.

Accordingly, it is to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A pulsed ultrasonic nebulizer system for flame spectroscopy, which comprises:

means for receiving a liquid sample to be analyzed; means for generating a pulsed RF signal; and transducer means responsive to said pulsed RF signal for nebulizing said liquid sample into an aerosol spray.

2. The pulsed ultrasonic nebulizer system according to claim 1, wherein said transducer means comprises a piezoelectric material for converting said pulsed RF signal into mechanical energy.

3. The pulsed ultrasonic nebulizer system according to claim 1, wherein said generating means comprises a

radio frequency power source and means for switching said power source on for a preselected time period that corresponds to the desired nebulization time for said liquid sample.

4. The pulsed ultrasonic nebulizer system according to claim 3, wherein said time period is within the range of approximately 0.4 to 8.0 seconds.

5. The pulsed ultrasonic nebulizer system according to claim 1, wherein said liquid sample receiving means is positioned adjacent said transducer means whereby said liquid sample contacts said transducer means prior to nebulization.

6. The pulsed ultrasonic nebulizer system according to claim 1, further comprising burner means for receiving and burning said aerosol spray.

7. The pulsed ultrasonic nebulizer system according to claim 6, wherein said burner means comprises a head having a plurality of apertures formed therein and a base whose upper end is in open communication with said head, said base having an inlet conduit for admitting a fuel-oxidizer mixture.

8. The pulsed ultrasonic nebulizer system according to claim 7, wherein said base of said burner means has a lower end opening in which said receiving means and said transducer means are positioned.

9. The pulsed ultrasonic nebulizer system according to claim 1, wherein said liquid sample ranges from 25 μ l to 200 μ l in volume.

10. A method of producing an aerosol of a liquid sample for flame spectroscopic analysis, which comprises the steps of:

providing a liquid sample to be analyzed; generating a pulsed RF signal; and nebulizing said liquid sample in response to said pulsed RF signal.

11. The method according to claim 10, wherein said step of generating a pulsed RF signal comprises the steps of:

generating a radio frequency signal; and switching said radio frequency signal on for a predetermined time corresponding to the desired nebulizing time of said liquid sample.

12. The method according to claim 10, wherein said nebulizing step comprises the steps of:

providing an ultrasonic transducer adjacent said liquid sample; and applying said pulsed RF signal to said ultrasonic transducer.

13. The method according to claim 12, wherein said step of generating a pulsed RF signal comprises the steps of:

generating a radio frequency signal; and switching said radio frequency signal on for a predetermined time corresponding to the desired nebulizing time of said liquid sample.

14. The method according to claim 13, wherein said predetermined time ranges from approximately 0.4 to 8.0 seconds.

15. The method according to claim 14, wherein the volume of said liquid sample ranges from 25 microliters to 200 microliters.

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