June 23, 1964 P. T. GILBERT, JR 3,138,330

NOZZLE AND PUMP FOR LIQUIDS

Filed Feb. 25, 1963

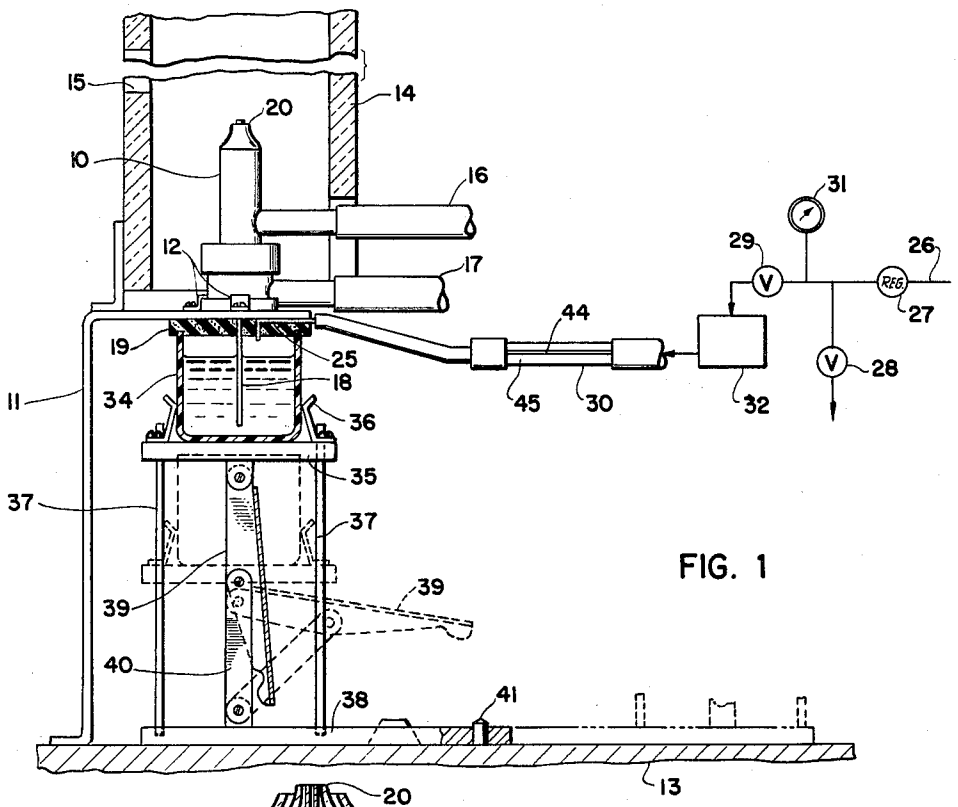


FIG. 1

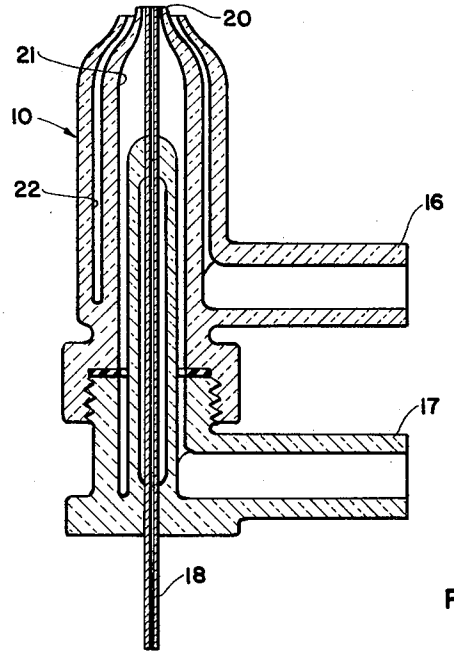


FIG. 2

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United States Patent Office 3,138,330 Patented June 23, 1964

3,138,330

NOZZLE AND PUMP FOR LIQUIDS

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Filed Feb. 25, 1963, Ser. No. 260,777
13 Claims. (Cl. 239—273)

This application is a continuation-in-part application of application Serial No. 16,378, filed March 21, 1960, and assigned to the assignee of the present invention.

This invention relates to the combination of an atomizer and a pump for generating a continuous and uniform flow of liquid sample. Whereas it is particularly effective for generating very low flow rates, such as 0.01 ml./min., and has been used for rates up to 3 ml./min., its utility is not necessarily confined to this range. Further, whereas the combination is particularly adapted for purposes of flame-spectrophotometric analysis, it is not limited to this application.

In flame photometry, the sample is most commonly supplied to the flame by means of a pneumatic atomizer. The suction created by the Venturi effect of a stream of gas flowing at high speed past or around the end of a capillary tube causes liquid, applied to the other end of the tube, to flow through it, being atomized on emerging into the stream of gas. The device thus serves the dual purpose of pumping the liquid sample and atomizing it. The gas used for atomization conveys the spray to the flame, of which it forms one of the constituents. A typical atomizer-burner is shown in my U.S. Patent No. 2,714,833.

In pneumatic atomization, the rate of liquid sample flow depends upon and is usually proportional to, the suction, which in turn is governed by the rate of gas flow. The sample flow rate thus cannot be controlled independently of the flow of gas that supplies the flame. This is inconvenient, for it is desirable in any such technique to have independent control of the significant variables, to permit their separate optimization. Accordingly, it is an object of the present invention to provide the combination of an atomizer and a pump wherein the liquid sample flow rate may be controlled independently of the gas flow rate.

Further, in pneumatic atomization the liquid sample flow rate will be altered by any accidental alteration of the gas flow rate, such as results from partial clogging of the gas port by dirt; or by any accidental change of configuration of the parts of the atomizer, such as results from thermal expansion of parts on heating by the flame, shifting of an insecurely fastened capillary, or accumulation of deposits (e.g., salts left by evaporation of the sample solution) upon the tip of the capillary or gas port. The sample flow rate is also affected by the effect of nature of the gas and of the sample itself upon the suction. Thus, the presence of hydrogen, which diffuses very rapidly, in the proximity of the capillary tip may drastically reduce the suction. If hydrogen is used for atomization, it will generate much less suction than an equal flow of heavier gas. Since the sample itself forms part of the environment of the capillary tip, it is likely that different samples, with their different vapor pressures, densities, etc., will somewhat affect the suction in the same way. It is another object of the invention to provide the combination of an atomizer and a liquid sample pump that does not utilize suction and is independent of the vagaries of flow rate inherent in suction type pumping.

Further, in causing the liquid sample to flow, the suction must act against any hydrostatic head that is effective. The sample is commonly fed in a vertical direction, usually upward but often downward. Any change in the

hydrostatic head of the liquid sample will correspondingly change the net or total effective suction available for pumping the sample. Such change occurs as the sample in a cup or in a funnel declines in level as it is consumed. This causes a gradual decline of the flow rate of the sample. Another object is to provide the combination of an atomizer and a liquid sample pump in which the rate of flow of the sample is independent of the quantity of sample present.

Further, uniformity of liquid sample flow rate depends upon constancy of the impedance imposed upon the sample by the capillary. This impedance depends upon the dimensions of the capillary bore and upon the viscosity of the liquid sample. Anything that alters either of these will change the flow rate. Thus, particles caught in the narrow capillary will obstruct the flow, as will also a deposit gradually forming upon the inner walls of the capillary. Blood plasma readily forms such a deposit. This difficulty becomes the greater, the smaller the capillary tube. Small tubes—i.e., tubes of high impedance—are desirable in flame photometry because they permit and require the high suctions generated by high gas pressures, which cause finer atomization and more efficient excitation in the flame and also suppress the effects of hydrostatic head, while keeping the sample flow down to the low rates necessary for optimal excitation of the elements in the sample. But realization of the best conditions in these respects may require a capillary tube only a few thousandths of an inch in diameter, which becomes clogged with extreme ease.

Capillary tubes also become clogged very easily by bubbles, which restrict the liquid sample flow. These bubbles tend to deposit within the capillary owing to the reduction of pressure experienced by the sample as it enters the capillary. This phenomenon can be avoided by deaerating the sample or by adding wetting agents, but both expedients are inconvenient and can in fact be interdicted by the nature of the sample. Bubbles also form very commonly by a hydrodynamic effect at the capillary inlet. If the inlet has sharp edges, the stream of liquid sample as it enters on first application of the sample will, by virtue of its inertia, resist the sudden change of direction imposed by the geometry of the inlet, and tend to skip a small area on the inner wall of the capillary just above the inlet. An air bubble is thereby trapped. Deaeration will not alleviate this difficulty. In some types of atomizer the formation of bubbles is one of the commonest sources of error. It is an object to provide the combination of an atomizer and a pump in which the rate of flow of the liquid sample is substantially independent of the dimensions of the capillary tubes, permitting the tubes to be selected for optimizing other variables.

A pneumatic suction atomizer pumps liquid sample at a rate proportional to its fluidity. Viscosity depends upon the nature of the sample, the concentration and nature of solutes dissolved in it, and the temperature. Flame photometry is a relative or comparative method of analysis; the sample must always be compared with a standard solution. It is of prime importance that the sample and standard solutions flow at the same rate. Since the sample is often of unknown composition, it may not be convenient to prepare a standard having the same viscosity. Further, viscosity is a very sensitive function of temperature. Any slight differences of temperature between liquids to be compared can lead to corresponding errors. Warming by the proximity of the flame or cooling by evaporation of a volatile solvent will introduce similar errors. Another object is to provide the combination of an atomizer and a pump therefor having

a controllable flow rate that is substantially independent of the viscosity of the liquid sample being pumped.

Atomizers for commercial instruments should be as nearly alike in their dimensions and characteristics as possible, to permit interchange and standardization of analytical methods. The manufacture of atomizers having the desired close tolerances of performance is exceedingly difficult, as the dimensions and smoothness of surfaces are very critical. Although subjected to the most rigorous inspection, commercial atomizers are never truly interchangeable.

In the manufacture of atomizer-burners an effort is generally made to adjust the dimensions and prescribe the fuel gas pressures in such a way as to assure that for most analytical emissions the intensity will be maximal with respect to sample flow rate. Unfortunately, different spectral lines or bands of different elements attain maximal intensity at different flow rates. Thus the prescribed pressures for a given atomizer-burner are necessarily a compromise. A pneumatic suction atomizer-burner does not permit simultaneous optimization with respect to all three variables: fuel flow, oxidant flow, and sample flow. This difficulty is particularly marked with hot flames such as premixed oxyacetylene and most especially with oxygen-cyanogen, in which the slightest departure from optimal flow adjustment can very greatly diminish the analytical sensitivity.

A pneumatic atomizer injecting liquid sample directly into the base of a flame (an atomizer-burner) can operate only with flames of high burning velocity or with pilot flames to maintain combustion, owing to the necessary high speed of the emerging gas. In the case of oxyacetylene, which is particularly advantageous for flame photometry, it may be desired to atomize the sample with premixed oxyacetylene. Owing to danger of detonation, such a mixture should not be compressed above 15 p.s.i.g. Since a mixing manifold must be interposed, there must generally be a pressure drop between the pure acetylene and the mixture, wherefore the mixture itself is not readily utilized at pressures as high as 15 p.s.i.g. But suction and atomization become less efficient at the lower pressures. Further, if a pneumatic suction atomizer is to be used in a spray chamber with premixed oxyacetylene or oxyhydrogen, the higher burning velocities of these mixtures entail an appreciable pressure drop across the burner port. This pressure drop imposes a burden upon the atomizer, acting like the hydrostatic head mentioned above. Accordingly, it is an object of the invention to provide the combination of a liquid pump and an atomizer-burner in which the liquid sample flow rate is not dependent on burner geometry nor on fuel or oxidant flow rates.

The available amount of certain samples (e.g., blood from a small mammal) may be so small as to be inadequate for flame-photometric analysis with a given instrument. It is known that in an instrument optimized for emission intensity, reduction of liquid sample flow rate does not entail a proportional loss of intensity. Indeed, a 10-fold reduction of flow may cause a loss of only 50% of the signal. The possibility of adjusting the sample flow rate independently of the flame adjustment and to a rate below the flow rate that would normally occur from mere suction alone is therefore valuable in conserving a scarce sample. With the usual suction atomizers this is not practical.

In general, the invention contemplates pumping of the liquid sample by means of a constant but adjustable flow of fluid provided by supplying a gas or liquid under controlled pressure to a very fine leak. The fluid emerging from the leak acts as a piston to force liquid sample from a closed cup through a small tube or capillary to the atomizer. The cup containing the liquid sample may be sealed by merely being pressed against a soft gasket. The sample thus touches no additional object except the atomizer to which very little sample adheres. In general, no rinsing is needed. By proper construction of the cup holder and the mechanism for moving it, samples can be changed in very rapid sequence.

It is an object of the invention to provide the combination of an atomizer and a pump for liquid sample including a sample container, a cover for sealing engagement with the container, an outlet capillary projecting into the container, an inlet capillary projecting into the container, and means for supplying fluid at a constant rate of volume flow through the inlet capillary for moving sample out of the container through the outlet capillary. A further object is to provide the combination of an atomizer and a pump wherein the pump includes a leak connected between a source of fluid under pressure and the inlet to the sample container with the leak having a flow impedance that is high relative to any impedance imposed upon the flow of the liquid sample, so that the fluid functions as a piston displacing the sample from the container, with the fluid piston being generated at a constant rate. Another object is to provide the combination of an atomizer and a pump having continuously variable pumping speeds over a wide range of flow rates, with the flow rate being settable to any desired value within a range in a matter of seconds and with different ranges being available by merely changing the leak in the inlet line.

It is an object of the invention to provide the combination of an atomizer and a pump which reduces the hazard of analyzing highly volatile and combustible material, such as gasoline, by flame photometry. A further object is to provide the combination wherein the sample is fully enclosed and hermetically separated from the surrounding air thereby preventing evaporation and change of temperature and concentration.

It is an object of the invention to provide the combination of an atomizer and a pump which eliminates the inconvenience of cleaning, washing, rinsing, or changing auxiliary equipment such as syringes, cylinders, or flexible tubing. Only the sample cup, a simple cylindrical container of polyethylene, Teflon, glass, or the like, need be rinsed between uses. Often a water repellent cup, such as one coated with a silicone water repellent, can be simply shaken dry and requires no cleaning. Another object of the invention is to provide the combination of an atomizer and a pump for liquid samples wherein the pump is inexpensive and requires no moving parts and can be incorporated into existing commercial flame photometers and other instruments with only minor modifications.

While the invention is described herein in conjunction with an atomizer-burner for a flame photometer, it is also applicable to other fields such as chromatography, electrophoresis, and fermentation, where accurate control of liquid sample flow is needed, often at low rates. The invention is also useful as a means of supplying sample to other spectrochemical emission sources such as the arc and spark. The drawing merely shows and the description merely describes a preferred embodiment which is given by way of illustration or example.

In the drawing:

FIG. 1 is an elevation view of the pump used in conjunction with an atomizer-burner; and

FIG. 2 is an enlarged sectional view of a portion of the apparatus of FIG. 1.

An atomizer-burner **10** is mounted on a bracket **11** by clips **12**, with the bracket in turn mounted on a base **13**. A tubular shield **14** with an access port **15** may be mounted on the bracket **11** around the burner **10**. Fuel, such as hydrogen or acetylene, is connected to the burner through a line **16** and a combustion supporting and atomizing gas, such as oxygen, is connected to the burner through a line **17**. Suitable pressure regulators and rate of flow control valves may be positioned in each of the lines for individually controlling the fuel and atomizer gas flow rates. A small diameter tubing or capillary **18** is fixed within the burner and projects downward through the

bracket **11** and a gasket **19** fixed to the under side of the bracket. Typically, the tubing **18** will be a short length of stainless steel hypodermic tubing.

The internal arrangement of the atomizer burner **10** is shown in detail in FIG. 2 and may be identical to that shown in my previously mentioned patent No. 2,714,833. The upper end of the tubing **18** terminates at the discharge nozzle **20**. The line **17** for the atomizer gas communicates with an internal chamber **21** which terminates in an annular opening about the tubing **18**. The line **16** for the fuel communicates with another internal chamber **22** which terminates in an annular opening disposed about the atomizer discharge nozzle **20**.

Another tubing or capillary **25** is fixed to the under side of the bracket **11** and projects downward through the gasket **19**. Typically, this tubing is also a length of stainless steel hypodermic tubing. Means are provided for supplying a fluid which may be either a gas or a liquid at a constant rate to the tubing **25**. In the embodiment of FIG. 1, a source of gas under pressure is connected to line **26** having a presure regulator **27** therein. The output from the regulator is directed through a bypass valve **28** to the atmosphere and through a shut-off valve **29** to a pumping liquid reservoir **32**. The outlet of the reservoir **32** is connected to a leak **30** and the leak is connected in turn to the capillary **25**. A pressure gauge **31** provides an indication of the pressure at the output of the regulator **27**. When the pumping fluid is a liquid, the parts up stream from the shut-off valve **29** are utilized only for the purpose of pressurizing the pumping liquid, the rate of flow of the pumping liquid being dependent only upon the fluid leak **30** and the pressure of the gas source. Other methods of pressurizing the pumping liquid are readily available such, for example, as by imposing a static head of liquid, such as mercury, upon the pumping liquid. It should, of course, be understood that when the pumping fluid is a gas the pumping liquid reservoir **32** may be omitted and the shut-off valve **29** connected directly to the leak **30**. Thus, the pressurizing gas connected to the line **26** becomes the pumping fluid.

A container **34** is removably mounted on a platform **35** for movement upward into engagement with the gasket **19**. One preferred apparatus for rapidly raising and lowering and changing the container is shown in FIG. 1. The container is held onto the platform by spring clips **36**. The platform moves up and down along four guides **37** which, in turn, are supported on a plate **38**. A lever **39** is pivotally mounted at one end to the platform **35**. Another lever **40** is pivotally mounted between the plate **38** and a central point of the lever **39**. The two levers are dimensioned to coact as a toggle for locking the container in the upper position, as shown in solid lines in FIG. 1. The lever **39** may be manually rotated to the position shown in phantom lines in FIG. 1 to lower the container. When the container is lowered, the plate **38** may be rotated about the post **41** for removal and reinsertion of suitable containers.

The leak **30** has a very high flow impedance in comparison to the tubings **25** and **18** so that the leak substantially controls the rate of flow of the pumping fluid into the container **34**. Typically, if a gas is utilized as a pumping fluid the leak consists of a length of a noble metal wire **44** such as palladium, sealed into a hard glass capillary tube **45**. The leak will be a few centimeters in length. The capacity or flow rate of the leak is a function of the diameter and length of the wire and the area of actual contact between the metal and glass. On the other hand, if a liquid is utilized as the pumping fluid, because of the higher viscosity, an ordinary fine capillary or an orifice may be utilized. Typical leak rates for use with an atomizer-burner range from 0.03 to 0.20 ml./min. per 1 p.s.i. pressure drop across the leak. The rate for a particular leak can be varied by varying the setting of the valve in the associated pressure source. Different ranges may be obtained by substituting leaks of different lengths or different wire diameters.

Other examples of suitable leaks include a pinched metal tube, a very fine glass capillary, and a narrow tube packed with fine powder. It should also be understood that, particularly in the case where liquid is utilized as the pumping fluid, the leak itself may be made adjustable by the use of a needle valve or any other suitable adjusting means.

Typically, the pressure regulator **27** will be set to provide an outlet pressure in the range of 5 to 30 p.s.i.g. As the fluid flow rate through the leak into the container is extremely small, it is preferred to operate the system with the bypass valve **28** partially open to provide a higher flow rate through the regulator so as to improve the regulator operation. The bypass valve **28** also permits rapid bleeding of the system on reduction of pressure to diminish the pumping rate without waiting for the fluid to escape through the leak **30**.

In operating the apparatus, the fuel gas and atomizer gas flow rates are adjusted to the desired values. A container with a standard liquid is raised into engagement with the gasket **19** and the rate of flow of sample up the tubing **18** is adjusted to the desired value by choosing an appropriate leak and suitably setting the regulator **27**. Then the container is lowered and a container with a liquid sample is placed on the platform and raised into the operating position. The flow of gas to the fuel line and the oxidant line and the flow of fluid in the pumping line are not interrupted as one liquid sample is substituted for another. After the appropriate measurements are made, additional sample and/or standard liquids are placed in containers on the platform and raised to the operating position. The apparatus may be operated with various quantities of liquid sample in the container and containers of varying capacities may be utilized. Of course, all the containers must have approximately the same external dimensions so as to fit onto the platform and engage the gasket.

When a container of liquid sample is raised to the operating position of FIG. 1, the incoming fluid from the capillary **25** functions in the nature of a fluid piston forcing the liquid in the container up through the outlet capillary **18**. The contact pressure between the container and the gasket must be sufficient to provide a hermetic seal adequate to retain the pumping fluid. In this apparatus, the rate of flow of sample up the capillary **18** is independent of the rate of flow of gas in the fuel line **16** and in the oxidant line **17**. As the sample is forced through the outlet capillary, any tendencies for this line to clog, as referred to previously, are substantially without effect. Also, since the rate of flow of liquid sample is not a function of the size of the outlet capillary, a relatively large diameter tubing can be utilized.

It should be noted that in operating the apparatus utilizing a gas as the pumping fluid, a transient condition in the rate of flow of liquid sample up the outlet capillary occurs when the container is first raised into position. In a practical embodiment, the time constant of initial equilibration can be kept to about one second, which is equal to that often incorporated in the measuring system of a flame photometer to damp fluctuations of the flame. On the other hand, when the pumping fluid is a liquid, the equilibration time is substantially zero because of the noncompressibility of liquids. Apparatus constructed according to the embodiment of FIG. 1 is presently in use to provide liquid sample flow rates in the range of 0.01 ml./min. to 3 ml./min. and the apparatus of the invention may be constructed to provide flow rates which exceed this range in both directions.

As has been hereinbefore pointed out the pumping fluid may be either a gas or a liquid, each having its own inherent advantages and disadvantages, some of which are enumerated herein but which should be in no way considered exhaustive. It is apparent that due to the greater

viscosity of liquid the fluid leak does not have to be as fine as is necessary when gas is utilized therefore making the leak more easily fabricated. While gases are generally quite similar from the standpoint of viscosity, due to the wide range of viscosity available in liquids greater versatility of operating conditions is afforded when liquids are used as the pumping medium. If a large quantity of liquid sample is available, the sample itself can be utilized as the pumping fluid and the device is no longer limited by the amount of sample which can be conveniently contained in the sample container.

Thermal drifts are almost entirely eliminated when the pumping fluid is a liquid and it has been experimentally demonstrated that the time constant of equilibration is greatly shortened and does not increase with pumping time, as it does with a gaseous medium. The flow rate of the sample in the outlet capillary responds instantaneously to changes of pressure on the pumping liquid and any residual delay in response results from the flexibility of the container and the gasket which may be reduced without difficulty.

On the other hand, gas as a pumping fluid possesses some advantages over a liquid from the standpoint of contamination and cleanliness. As has been pointed out, it is the general practice to adjust the flow rates of the fuel gas, the atomizer gas, and the pumping fluid with a standard liquid in the container and to allow these to flow continuously as the standard liquid is removed and a container having a liquid sample to be analyzed is substituted therefor. It is obvious that if the pumping fluid is a liquid it must be disposed of during this transition or its flow interrupted by some suitable means. On the other hand, when a gas is used it is merely discharged to the atmosphere. Ordinarliy, this gas will be the same as that used for the atomizer and oxidant gas and, hence, usually will be oxygen. Further, when a gas is used considerations of contamination of the liquid sample generally do not arise as is the case where the pumping medium is a liquid.

Contamination of the liquid sample by a liquid pumping fluid in most instances may be overcome by appropriate utilization of the characteristics of the liquid sample and the pumping fluid. For example, a pumping liquid that is immiscible with the liquid sample may be chosen. If the pumping liquid is lighter than the liquid sample, the inlet capillary **25** can be kept shorter than the outlet capillary **18**, of FIG. 1, whereas if the pumping liquid is heavier than the liquid sample the outlet capillary **18** should be short, so as not to reach the bottom of the sample container. If for any reason it is desirable to utilize a pumping liquid that is miscible with the sample, then by due consideration being given to methods of inhibiting the diffusion of the pumping liquid with the sample, contamination may be minimized. For example, the container may be made tall and narrow to inhibit diffusion and if the pumping liquid is lighter than the sample the outlet and inlet capillaries are maintained as illustrated in FIG. 1. If, on the other hand, the pumping liquid is heavier than the liquid sample, the inlet capillary may be extended to the bottom of the container while the outlet capillary is shortened.

When a pumping liquid is utilized the inlet capillary **25** can be so placed, that in the absence of the sample container, the liquid will drip harmlessly into a waste container. Alternatively, a very volatile liquid can be selected that will evaporate completely in the absence of the sample container. A third expedient is to interrupt the flow of the pumping liquid.

While the preferred embodiment of the invention has been described with particularity as a pneumatic atomizer, it should be understood that other embodiments may utilize non-pneumatic atomizers such, for example, as atomizers of the electrostatic, ultrasonic or centrifugal type. In each of these cases, it is often desirable to supply a sample at the discharge nozzle of the atomizer at a constant rate of volume flow which may be readily accomplished with the present invention. While the exemplary embodiment of the invention has been disclosed and described with particularity, it will be understood that various changes, modifications and substitutions may be made without necessarily departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. In a pump for a liquid atomizer, the combination of:
a source of atomizer gas under pressure;
a discharge nozzle connected to said atomizer gas source for discharging said atomizer gas at said nozzle;
a closed container for liquid sample;
an outlet capillary providing a liquid sample flow path between said container and said discharge nozzle;
an inlet capillary projecting into said container;
and means for supplying a fluid at a constant rate of volume flow to said inlet capillary for moving liquid sample out of said container through said outlet capillary.

2. In a pump for a liquid atomizer, the combination of:
a source of atomizer gas under pressure;
a discharge nozzle connected to said atomizer gas source;
a source of pumping fluid under pressure;
a closed container for liquid sample;
an outlet capillary having one end positioned within said container and the other end positioned at said discharge nozzle;
an inlet capillary positioned within said container;
and a fluid leak connected between said pumping fluid source and said inlet capillary for supplying fluid at a constant rate of volume flow through said inlet capillary, said fluid leak having a flow impedance that is high relative to the flow impedance of said outlet capillary.

3. The combination of claim 1 wherein said pumping fluid is a liquid.

4. The combination of claim 2 wherein said pumping fluid is a liquid.

5. In a pump for a liquid atomizer, the combination of:
a source of atomizer gas under pressure;
a discharge nozzle connected to said atomizer gas source;
a closed container for liquid sample;
an outlet capillary providing a liquid sample flow path between said contianer and said discharge nozzle;
an inlet capillary projecting into said container;
and means for supplying a gas at a constant rate of volume flow to said inlet capillary for moving liquid sample out of said container through said outlet capillary, said means including a gas leak connected to said inlet capillary with said gas leak having a flow impedance that is high relative to the flow impedance of said outlet capillary.

6. In a pump for a liquid atomizer, the combination of:
a source of atomizer gas under pressure;
a discharge nozzle connected to said atomizer gas source;
a source of pumping gas under pressure;
a closed container for liquid;
an outlet capillary having one end positioned within said container and the other end positioned at said discharge nozzle;
an inlet capillary positioned within said container;
and a gas leak connected between said pumping gas source and the other end of said inlet capillary for supplying gas at a constant rate of volume flow through said inlet capillary, with said leak having a flow impedance that is high relative to the flow impedance of said outlet capillary.

7. The combination of an atomizer and a pump for supplying liquid sample to the atomizer for use in spectrochemical analysis; the combination comprising:
an atomizer having a discharge nozzle;

a container for a sample to be atomized by said atomizer;

an outlet capillary having one end positioned within said container and the other end positioned at said discharge nozzle;

an inlet capillary positioned within said container;

a fluid leak connected to said inlet capillary and adapted to be connected to a source of pumping fluid, said fluid leak when connected to said fluid source supplying said fluid at a constant rate of volume flow through said inlet capillary for displacing a sample in said container and moving said sample through said outlet capillary, said fluid leak having a flow impedance that is high relative to the flow impedance of said outlet capillary.

8. The combination of an atomizer-burner and a pump for supplying liquid samples to the atomizer-burner at a flow rate independent of the fuel gas and oxidant flow rates, the combination comprising:

an atomizer-burner having a discharge nozzle;

a sealed liquid sample container;

an outlet capillary having one end positioned at said discharge nozzle and the other end projecting into said container;

an inlet capillary projected into said container;

means for supplying a fluid at a constant rate of volume flow to said inlet capillary for moving sample out of said container through said outlet capillary.

9. The combination of an atomizer-burner and a pump for supplying liquid samples to the atomizer-burner at a flow rate independent of the fuel gas and oxidant flow rates, the combination comprising:

an atomizer-burner having a discharge nozzle;

a sealed liquid sample container;

an outlet capillary having one end positioned at said discharge nozzle and the other end projecting into said container;

an inlet capillary projected into said container;

means for supplying a fluid at a constant rate of volume flow to said inlet capillary for moving sample out of said container through said outlet capillary;

said means comprising a fluid leak connected to said inlet capillary with said leak having a flow impedance that is high relative to the flow impedance of said outlet capillary.

10. The combination of an atomizer-burner and a pump for supplying liquid sample to the atomizer-burner at a flow rate independent of the fuel gas and oxidant flow rates, the combination comprising:

an atomizer-burner having a discharge nozzle;

means for supplying fuel gas to said atomizer-burner;

means for supplying an atomizing gas to said atomizer-burner;

a sealed container for liquid samples to be atomized by said atomizer-burner;

an outlet capillary having one end positioned within said container and the other end positioned at said discharge nozzle;

an inlet capillary positioned within said container;

a source of fluid under pressure;

a fluid leak connected between said inlet capillary and said source of fluid for supplying said fluid at a constant rate of volume flow to said inlet capillary for moving the liquid sample out of said container through said outlet capillary.

11. The combination of claim 10 wherein said fluid leak has a flow impedance that is high relative to the flow impedance of said outlet capillary.

12. The combination of claim 11 wherein said fluid is a liquid.

13. The combination of claim 11 wherein said fluid is a gas.

References Cited in the file of this patent

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,138,330 June 23, 1964

Paul Thomas Gilbert, Jr.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 44, for "higher" read -- high --; column 7, line 10, for "can" read -- may --; column 8, line 46, for "contianer" read -- container --.

Signed and sealed this 17th day of November 1964.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents