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Coulter et al.

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[54] **METHOD AND APPARATUS FOR STUDYING PARTICLES HAVING WIDELY DIFFERENT SIZES**

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[51] **Int. Cl.** **G01n 27/00**

[58] **Field of Search** .... 324/71 CP; 73/432 PS

[56] **References Cited**

UNITED STATES PATENTS

3,444,463	5/1969	Coulter et al.	324/71 CP
3,444,464	5/1969	Coulter et al.	324/71 CP

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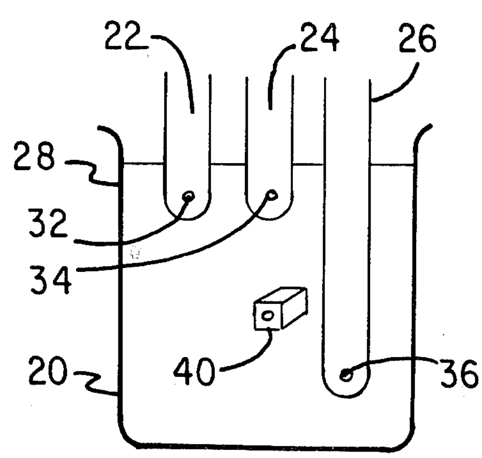
[57] **ABSTRACT**

An apparatus for studying particles of widely different sizes includes a vessel and a fluid medium in the vessel with the particles suspended thereon. First and second aperture tubes are suspended in the vessel at a first height, and a third aperture tube is suspended at a second lower height. The first aperture tube has an aperture of substantially smaller size than the second and third aperture tubes. The rate of entry through the aperture and into the second tube, of particles large enough to cause blockage of the first aperture in the first tube, is detected. When this rate drops below a first particular rate, indicating that substantially all particles greater than that size have settled below this particular height in the beaker, control circuitry is actuated to enable the fluid to enter into the first tube via the aperture therein for analyzing particles received therein via Coulter type detectors.

Control circuitry may also be initiated to allow fluid to enter the third tube through its aperture for analyzing the particles received therein via Coulter type detectors.

27 Claims, 2 Drawing Figures



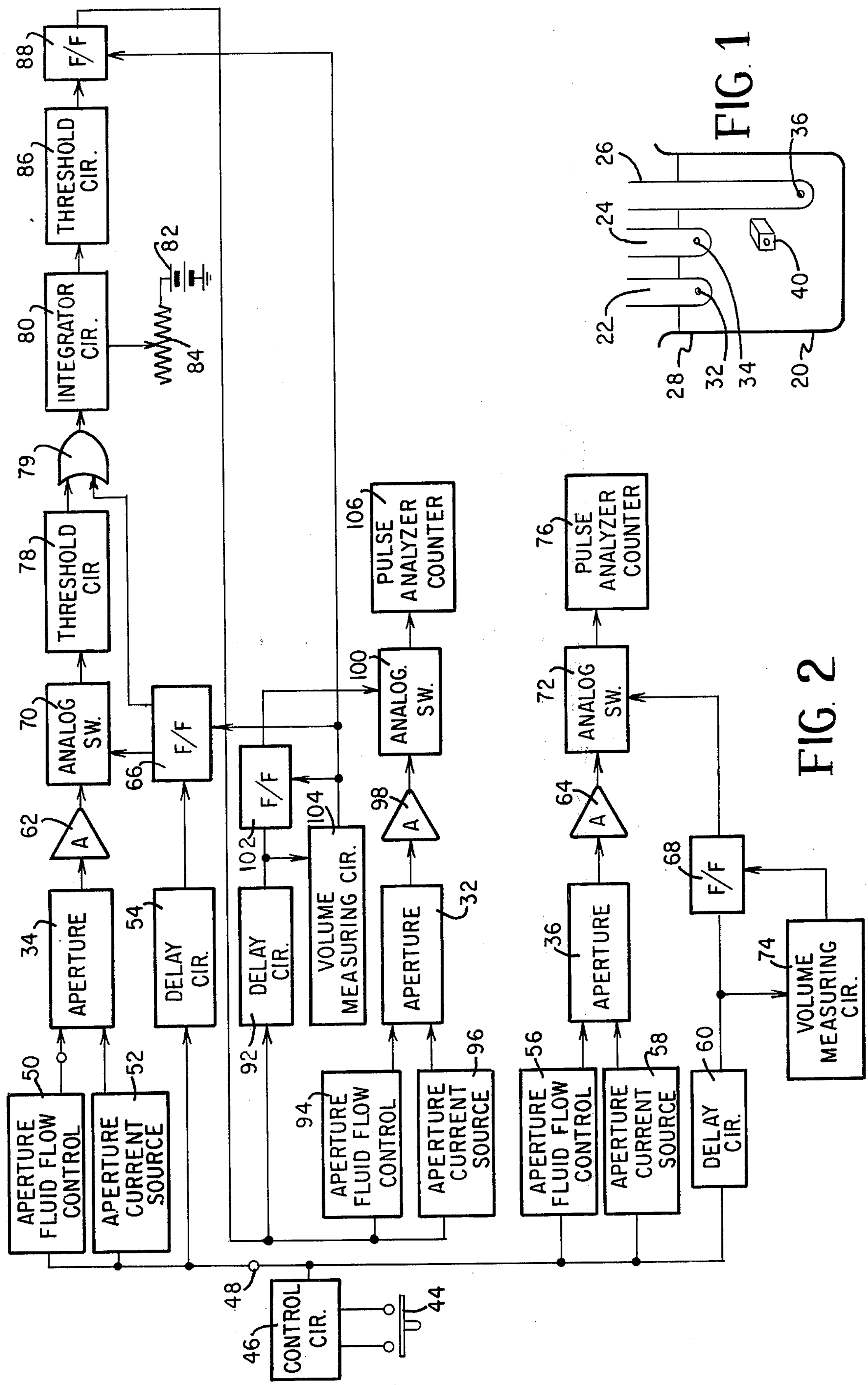

APERTURE FLUID FLOW CONTROL
APERTURE CURRENT SOURCE
APERTURE
A
ANALOG SW.
THRESHOLD CIR
INTEGRATOR CIR.
THRESHOLD CIR.
F/F
DELAY CIR.
VOLUME MEASURING CIR.
PULSE ANALYZER COUNTER
CONTROL CIR.

FIG 1

FIG 2

METHOD AND APPARATUS FOR STUDYING PARTICLES HAVING WIDELY DIFFERENT SIZES

BACKGROUND OF THE INVENTION

This invention relates generally to particle analyzing apparatus of the type on which particles suspended in a fluid medium are caused to move through an electric current path of small dimensions, and more particularly to a structure enabling use of such apparatus for studying particles having widely different sizes.

Now well known in the art are apparatus and techniques based upon the principles of operation pioneered by Wallace H. Coulter, one of the present inventors. According to the principles and techniques of Coulter, an electronic counting and sizing apparatus, hereinafter termed the Coulter type apparatus, is provided such as is claimed in and described in U.S. Pat. No. 2,656,508. The Coulter apparatus produces an electrical signal each time that a particle suspended in a fluid passes through an electric current path of small dimension, which, in the first commercial apparatus, is constricted by a minute aperture in a wall of insulating material disposed between two bodies of the fluid. The apparatus includes means for moving the fluid through the aperture to carry the particles along with the fluid; a source of electric current, electrodes immersed in the fluid on opposite sides of the wall and connected to the source of current providing a constricted current path between the electrodes and through the aperture, a detector connected to the electrodes and responsive to the changes in resistance or electrical impedance of the aperture contents each time that a particle passes therethrough to develop a detection signal, and some form of counter to respond to the signals detected.

In its various forms, the apparatus is known and sold throughout the world under the trademark "Coulter Counter." The Coulter type apparatus will include means for moving the fluid, such as a syphon or manometer; means for metering the fluid such as a metering device of the type described in U.S. Pat. No. 2,869,078; means for containing the fluid such as vessels, beaker tubes, conduits and the like; means for coupling the current source and detector to the fluid, such as electrode systems and leads; and means for establishing a minute opening or aperture in the wall between bodies of fluid such as the aperture formed in a wafer or other member set into a wall of a glass tube immersed in a vessel of sample fluid. The aperture in effect "scans" the suspension passing through it and reference will be hereinafter made to the portion which produces the signals as a scanning system.

Since the amplitude of the signal generated by the passage of a particle through the aperture is proportional to the volume of the particle, the apparatus has been widely used for sizing as well as counting. Multiple apertures, however, must be employed if particles of widely varying sizes are to be counted and sized. This is because the use of a single aperture of a compromise diameter results in a decreased sensitivity of the aperture to the small particles, and the possibility of increased coincidence loss for a given particle concentration. It could also introduce an error in linear response to particles greater than 20 or 30 percent of the aperture diameter. Generally in such arrangements multiple dilutions are required to get the best results. It also required scalping or decanting to prevent blockages by large particles.

Various applications have been made utilizing multiple channels for obtaining statistical information on size distribution and for studying particles having widely different sizes. One such apparatus is described in U.S. Pat. No. 3,603,875. Such systems are particularly important in industrial systems wherein particle size and concentration must be determined for a vast gamut of materials such as, for example, slurries, dusts, powders, emulsions, and the like. Although the Coulter type apparatus has replaced Stokesian methods involving sedimentation, such apparatus has been somewhat troubled by aperture blockage in systems wherein the particles to be detected vary greatly in size. These problems have been recognized and a number of solutions have been implemented. For example, U.S. Pat. 3,259,842 describes a debris alarm which indicates the blockage of the aperture so as to allow the technician to clear the aperture blockage and reinstitute use of the apparatus. U.S. Pat. 3,444,463 describes a system wherein parallel samplings are taken so that one sampling may be discarded in the event the aperture becomes blocked.

In these and other related patents, the solution has always been to compensate after a blockage has occurred such as for example by voting out the sampling taken from the blocked aperture, or by statistically manipulating the data taken at the time of blockage in order to yield a reasonably correct result from the data obtained from the blocked aperture. The user in all cases is still presented with the problem of partially dismantling the apparatus in order to clear the blockage from the apparatus, or employing automatic equipment which is a part of the apparatus in order to remove the blocking particle from the aperture. These systems do not attempt to forestall blockage of an aperture of small dimensions by a particle of large dimensions.

SUMMARY OF THE INVENTION

In practicing this invention an apparatus is provided for sizing and counting particles of widely differing sizes which uses the Coulter principle. The apparatus includes a first vessel carrying a body of fluid having particles suspended therein of widely varying size. First, second and third tubes, having first, second and third apertures therein respectively for enabling flow of fluid from the vessel into the tubes are positioned in the vessel. The first and second tubes are positioned at a first height in the vessel and the third tube is positioned at a second lower height in the vessel. The third aperture is large enough to accommodate the largest particle in the fluid suspension. The first aperture in the first tube is substantially smaller than the second and third apertures. First, second and third fluid control systems are coupled respectively to the first, second and third tubes for causing the fluid to flow from the vessel through the apertures into the tubes. An actuating device is provided for actuating the second and third fluid control systems for enabling flow of fluid through the second and third apertures. First, second and third scanning systems are provided and are coupled respectively to the first, second and third apertures. Each of the scanning systems is responsive to the passage of each particle through the aperture associated therewith to produce an electric signal the value of which is related to the dimensions of the particle. Threshold circuitry is coupled to the second scanning system and is operative in response to the reduction in the repetition

rate of electric signals in excess of a particular value, indicating a reduction in the number of particles in excess of a particular size, to develop a control signal. The first fluid control system is operative in response to the control signal to enable flow of fluid from the vessel through the first aperture into the first tube. Signal analyzers are also provided and coupled to the scanning systems attached to the first and third tubes. The signal analyzers analyze the electric signals produced by the first and third scanning systems for providing indications of particle size and concentration.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial representation of the beaker and aperture tubes used in the apparatus of this invention;

FIG. 2 is a block diagram of the automatic circuitry used in the apparatus of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, there is shown a vessel **20** which may be a simple beaker. Three tubes **22, 24,** and **26** are partially immersed in a body of fluid **28.** Tubes **22** and **24** are immersed to substantially the same depth beneath the surface of fluid **28,** and tube **26** is immersed to a substantially greater depth than tubes **22** and **24.** Tube **26,** in the preferred embodiment, is positioned close to the bottom of beaker **20,** and tubes **22** and **24** are positioned somewhat near the surface of fluid **28.** Tubes **22, 24** and **26** are called aperture tubes because they each have microscopic apertures **32, 34,** and **36** respectively therein. Aperture tube **22** has a small aperture **32,** relatively speaking, whereas aperture tubes **24** and **26** have large apertures **34** and **36** relatively speaking. For example, aperture **32** can be 50 microns in diameter whereas apertures **34** and **36** can be 250 or even 500 microns in diameter. Although apertures **34** and **36** have a size ratio with respect to one another of as much as two to one, for purposes of this application, they are considered substantially the same in size.

Vessel **20,** aperture tubes **22, 24** and **26,** and fluid **28,** constitute portions of a Coulter type particle analyzer such as is well known in the art. Such apparatus is shown and described in U.S. Pat. No. 2,656,508. Multiple aperture fittings, which may for example be employed for at least the aperture **22** and **24,** are shown and described in U.S. Pat. No. 3,444,464; and a particle analyzing apparatus for use with the multiple aperture fittings is shown and described in U.S. Pat. No. 3,444,463.

Particles to be analyzed are suspended in fluid **28** which is poured into beaker **20.** It is to be understood, of course, that the particles to be analyzed which are suspended in fluid **28** vary greatly in size. In any small increment of volume, such as **40,** the particles entering the volume from above, will equal the particles leaving the volume from below, as long as the distribution of particle sizes is relatively uniform throughout fluid **28.** However, as the large particles settle faster than the small and medium size particles a point in time will be reached when the large particles no longer enter volume **40** at the same rate from the top as they leave from the bottom. If the increment of volume **40** is located for example at the level of apertures **32** and **34,** a point will be reached where there are no particles larger in size than the aperture **32,** or large enough to block aperture **32.** To digress for a moment, it should be understood

that if for example aperture **32** is 30 microns in size, multiple or odd-shaped particles greater in size than 10 microns can cause blockage of aperture **32.** It then will not be possible to block aperture **32.** However, smaller particles of interest are still present at the height of the aperture **32** at this time and it is desired to analyze these particles.

In operation, the fluid **28,** with particles to be analyzed suspended therein, is either allowed to flow through apertures **34** and **36** of aperture tubes **24** and **26,** or is forced to so flow. As particles pass through aperture tubes **24** and **26,** they will cause particle pulses to be developed, in accordance with the well known Coulter principle, having amplitudes proportional to the size of the particle passed through the aperture. Those pulses developed in response to passage of particles through aperture **36** will be at least counted. The rate at which pulses in excess of a particular amplitude, representing particles large enough to block aperture **32,** are developed, in response to passage of particles through aperture **34,** will be monitored. When the rate decreases below a predetermined point, thus indicating that statistically very few particles large enough to block aperture **32** are present at that height in fluid **28,** circuitry will be activated to allow fluid **28** to flow through aperture **32** in aperture tube **22,** or to force fluid **28** to so flow. That is, when the concentration of particles large enough to block aperture **32,** and at or above the height of aperture **32,** decreases below a concentration which will cause blockage of aperture **32,** fluid **28** will be allowed to flow into aperture **32.** Small particles suspended in fluid **28** can then be analyzed by passage through aperture **32,** without fear of blocking aperture **32** by a larger particle.

Referring now to FIG. **2** which is the block diagram of the apparatus, when fluid **28** in FIG. **1** has been entered into beaker **20** for a period of time sufficient to allow particles to begin to settle down through fluid **28,** push button **44** can be depressed. Actuation of push button **44** causes actuation of control circuit **46.** Control circuit **46** may, for example, be a device which changes state in response to actuation of push button **44** and develops a control voltage at conductor **48.** This control voltage is coupled via conductor **48** to aperture fluid flow control **50,** aperture current source **52,** delay circuit **54,** aperture fluid flow control **56,** aperture current source **58** and delay circuit **60.** Aperture fluid flow control **56** and aperture fluid flow control **50** in the preferred embodiment are suction devices attached to tubes **24** and **26** respectively. Some fluid flow control devices are illustrated in U.S. Pat. Nos. 2,869,078 No. 3,015,775. Fluid flow control devices **50** and **56** when actuated cause fluid **28** to flow from beaker **20** through apertures **34** and **36** of aperture tubes **24** and **26** respectively.

Aperture current source **52** and aperture current source **58** operate upon the above noted Coulter principle. Both include a source of power or power supply and two electrodes immersed in fluid **28.** One of the two electrodes may be common to both aperture current source **52** and aperture current source **58.** A second electrode for aperture current source **52** is positioned in aperture tube **24,** and a second electrode for aperture current source **58** is positioned in aperture tube **26.**

Aperture current source **52** and aperture current source **58** are coupled to control circuit **46** via conductor **48**, and will be actuated in response to the control signal from the control circuit **46**. When actuated they will develop a current path between the electrodes and through apertures **34** and **36** respectively. Particles passing through apertures **34** or **36** will cause modulation of the current paths in accordance with the now well known Coulter principle which in turn will cause a pulse to be developed whose amplitude is related to the size of the particle passing through the aperture. In FIG. **2**, pulses developed in response to passage of a particle through aperture **34** are shown as being coupled from aperture **34** to amplifier **62**, and pulse developed in response to particles passing through aperture **36** are shown as being coupled from aperture **36** to amplifier **64**.

The control signal developed at conductor **48** by control circuit **46** is also coupled to delay circuits **54** and **60**. Delay circuits **54** and **60** may, for example, consist of a monostable and trailing edge detector, coupled in series and operative in response to the control signal to develop a delay signal a predetermined period of time after the control signal. The purpose of delay circuits **54** and **60** is to provide a delay sufficient to allow aperture fluid flow controls **50** and **56** and aperture current sources **52** and **58** to reach an equilibrium condition or steady state. In another embodiment, delay circuits **54** and **60** would be contacts of a manometer syphon structure which would be part of aperture fluid flow controls **50** and **56**. Such contacts are shown and described in U.S. Pat. No. 3,259,842. The delay signals developed by delay circuits **54** and **60** are coupled to bistable multivibrators **66** and **68** respectively. Bistable multivibrators **66** and **68** in the preferred embodiment are RS type flip-flops most commonly known in the art as "RS flip-flops." The delay circuit signals are coupled to the "set" inputs of flip-flops **66** and **68** causing them to change states and develop a logical "one" signal at their outputs. The logical "one" signals developed by flip-flops **66** and **68** are coupled to the control inputs of analog switches **70** and **72** respectively.

The delay signal developed by the delay circuit **60** is also coupled to volume measuring circuit **74**. Volume measuring circuit **74** is operative in response to the delay circuit signal to begin measuring the volume of fluid **28** passing throuogh aperture **36** in aperture tube **26**. When volume measuring circuit **74** has measured a predetermined volume of fluid **28** passing through aperture **36**, it will develop a reset signal which is coupled to the reset input of the flip-flop **68** causing flip-flop **68** to reset and revert to its original state. With flip-flop in its original state, it will develop a logical "zero" at its output which is coupled to the control input analog switch **72**. Volume measuring circuit **74** in one embodiment is a portion of aperture fluid flow control **56**. In such a system, volume measuring circuit **74** would be a second contact of a manometer syphon structure which would be closed after a predetermined metered amount of fluid **28** has passed through aperture **36**. Such a contact arrangement is also shown and described in U.S. Pat. No. 3,259,842.

Analog switch **72** operates such that when a logical "one" is coupled to its control input from flip-flop **68** it will couple the pulses developed in response to passage of particles through aperture **36**, and amplified by amplifier **64**, from amplifier **64** to pulse analyzer counter **76**. Pulse analyzer counter **76** is of the type now well known in the art which will count each pulse. Pulse analyzer counter **76** can also analyze certain characteristics of the pulse, such as for example, its amplitude and/or duration in order to ascertain certain characteristics of each particle detected, such as for example, the particle size and shape. It is to be understood that aperture **36** as noted above is quite a large aperture. As a consequence, particles passing through aperture **36** which are smaller than a predetermined percentage of the size of aperture **36**, say for example 3 percent of the aperture size, will not adequately be sensed. Either a pulse will not be developed in response to passage of such particles through aperture **36**, or the pulse will not have sufficient amplitude and duration to allow pulse analyzer/counter **74** to operate.

Analog switch **70** is identical to analog switch **72** and operates such that when a logical "one" is coupled to its control input from flip-flop **66** it will couple the pulses, developed in response to particles passing through aperture **34**, and amplified by amplifier **62**, from amplifier **62** to threshold circuit **78**. Threshold circuit **78** is operative only in response to pulses in excess of a predetermined amplitude to develope a threshold signal. The threshold amplitude of threshold circuit **78** is selected such that it is equal to an amplitude corresponding to a particle size which will block aperture **32** in aperture tube **22**. The threshold signals developed by threshold circuit **78** are coupled through OR gate **79** to the reset input of integrator circuit **80**.

A source of potential such as battery **82** is coupled to integrator circuit **80** through potentiometer **84**. Integrator circuit **80** is operative in response to the current from battery **82** to develop an integration voltage. Integrator circuit **80** will discharge this integration voltage in response to the threshold signal coupled to the reset input of integrator circuit **80** through or gate **79** from threshold circuit **78**. In operation, then each time a particle which is large enough to block aperture **32** in aperture tube **22** passes through aperture **34** of aperture tube **24**, threshold circuit **78** will develop a threshold signal which is coupled through OR gate **79** to integrator circuit **80** causing it to discharge the integration voltage developed. If the rate at which particles large enough to block aperture **32**, and passing through aperture **34** decreases below a predetermined rate, thus indicating the relative absence of particles large enough to block aperture **32**, integrator circuit **80** will not discharge often enough and will develop an integration voltage in excess of that necessary to actuate threshold circuit **86**. Threshold circuit **86** will develop a threshold signal when the integration voltage developed by integrator citcuit **80** exceeds its threshold level which is coupled to an input of bistable **88**. In the embodiment shown, bistable **88** is an RS flip-flop just as flip-flops **66** and **68**, and threshold circuit **86** is coupled to the "set" input. Flip-flop **88** is operative in response to the threshold signal coupled from threshold circuit **86** to develop a logical "one" which is coupled to delay circuit **92**, aperture fluid flow control **94** and aperture current source **96**.

A second output of flip-flop **66** is coupled to the reset input of integrator circuit **80** through a second input of OR gate **79**. This second or "not" output develops a logical "one" when flip-flop **66** is reset or in a nonactivated state, and develops a logical zero when flip-flop **66** is in its second state. That is, the not output will develop a logical "one" when the regular output develops a logical "zero," and will develop a logical "zero" when the regular output develops a logical "one." The connection to the reset input of integrator circuit **80** maintains integrator circuit **80** in a reset state until such time as aperture fluid flow control **50** and aperture current source **52** are actuated, stabilize, and fluid **28** is flowing through aperture **34** in a stable fashion so that particles can be detected.

Aperture fluid flow control **94** and aperture current source **96** are identical to aperture fluid flow control **56** and aperture current source **58.** Aperture fluid flow control **94** will operate in response to the logical "one" coupled from flip-flop **88** to allow fluid **28** to flow through aperture **32** into aperture tube **22.** Aperture current source **96** will operate in response to the logical "one" coupled from flip-flop **88** to develop a current path through aperture **32** in aperture tube **22.** The passage of particles through aperture **32** will cause pulses to be developed, as described above with respect to the passage of particles through aperture **36,** which are coupled to amplifier **98.** Amplifier **98** amplifies the pulses and couples them to the input of analog switch **100.**

Delay circuit **92** is identical in operation to delay circuit **60** previously described and will develop a delay signal a predetermined period of time after receipt of a logical "one" from flip-flop **88.** The predetermined period of time is provided in order to allow aperture fluid flow control **94** and aperture current source **96** to reach an equilibrium condition. The delay signal is coupled to the set input of flip-flop **102** and to the input of volume measuring circuit **104.** Flip-flop **102** will change states in response to the delay signal and develop a logical "one" at its output which is coupled to the control input of analog switch **100.** Analog switch **100** is operative in response to the logical "one" coupled to the control input to allow the amplified pulses developed by amplifier **98** to be coupled to pulse analyzer **106** for counting and analysis of the pulses. It is to be understood again, that aperture **32** is much smaller than apertures **34** and **36** so that counting and analysis of the small particles suspended in fluid **28** can be accomplished simultaneously with counting and analysis of large particles via aperture **36** and pulse analyzed counter **76,** and without fear of clogging or blocking aperture **32** by the presence of large particles.

Volume measuring circuit **104** is substantially the same as volume measuring circuit **74** and will operate in response to the delay signal from delay circuit **92** to begin measuring the volume of fluid **28** passing through aperture **32** in aperture tube **22.** When a predetermined volume has been measured, volume measuring circuit **104** will develop a reset signal which is coupled to the reset input of flip-flops **102, 66** and **88** causing them to reset and revert to their original state. With flip-flop **102** reset a logical "zero" is coupled to the control input of analog switch **100,** thus terminating the counting and analysis by pulse analyzer counter **106** of particles passing through aperture **32.** The reset pulse coupled to flip-flop **88** will cause it to reset thus terminating further operation of aperture fluid flow countrol **94** and aperture current source **96.** The reset signal coupled to flip-flop **66** will cause it to reset thus closing analog switch **70** and preventing pulses from being coupled from amplifier **62** to threshold circuit **78.**

It is to be understood that further modifications and adaptations of the above noted circuitry are contemplated as being within the scope of this patent. For example, control circuit **46** can develop separate control signals for aperture fluid flow control **50** and aperture current source **52,** delayed in time compared to the other control signals it develops. The delay allows the largest particles in fluid **28** to settle below the height of apertures **32** and **34.** This allows use of an aperture **34** which is smaller than aperture **36,** for example, by a ratio of two to one. Aperture **34** of course must still be substantially larger than aperture **32.** Control circuit **46** may include an automatic reset which can be coupled to the output of volume measuring circuit **104.** The signal developed by volume measuring circuit **104** when the appropriate volume of fluid **28** passing through aperture **32** has been measured can then be used to reset or terminate operation of the entire system. Furthermore, alternative arrangements for turning off all or part of the total system either simultaneously or sequentially can be envisioned so that the system is prepared to begin a new measurement cycle.

What it is desired to be secured by letters Patent of the United States is:

1. A method for studying particles of widely different sizes wherein the particles are suspended in a liquid medium in a vessel and settle through the medium from top to bottom at a rate determined by their size, said method including the steps of:

detecting the concentration at a particular height in said vessel of particles suspended in said liquid medium in excess of a particular size,

allowing the liquid medium and particles suspended therein to pass through a first aperture in a first tube positioned at said particular height in said vessel in response to said concentration at said particular height decreasing below a first detected concentration, and

allowing the liquid medium and particles suspended therein to pass into a second tube, at a second particular height on said beaker through a second aperture substantially greater in size than said first aperture.

2. The method of claim **1** further including the steps of:

detecting each particle suspended in said liquid medium passing into said first tube through said first aperture,

detecting each particle suspended in said liquid medium passing into said second tube through said second aperture.

3. The method of claim **2** wherein said step of detecting each particle passing into said first and second tubes includes the step of generating an electrical signal in response to passage through one of said first and second apertures of a particle suspended in said fluid medium, and processing said electrical signal to at least separately count said particles passing into said first and second tubes.

4. The method of claim **3** wherein the value of said electrical signal is related to the dimensions of the particle and further including the step of processing said electrical signal to determine said dimensions.

5. The method of claim **1** wherein said step of detecting the concentration includes,

allowing the liquid medium to pass through a third aperture substantially greater in size to said first aperture,

detecting particles passing through said third aperture and greater in size than said particular size, detecting a decrease in the rate of passage through said third aperture of particles in excess of said particular size.

6. The method of claim 5 wherein the step of detecting said concentration includes the step of,

generating an electrical signal in response to passage through said third aperture of a particle greater in size than said particular size,

detecting the repetition rate of said electrical signals,

detecting a decrease in the repetition rate of said electrical signals below a predetermined repetition rate.

7. The method of claim 1 wherein the steps of allowing said liquid medium to pass includes the step of creating a pressure differential between said vessel and said first and second tubes for drawing said liquid through said first and second apertures.

8. The method of claim 7 wherein said step of creating a pressure differential includes the step of creating a vacuum in said first and second tubes.

9. An apparatus for studying particles of widely different sizes suspended in a fluid by passage of said fluid from a vessel to one of a plurality of tubes positioned in said vessel wherein each of said plurality of tubes has an aperture therein for passage of said fluid therethrough, said apparatus comprising,

at least a first and second of said plurality of tubes positioned at a first height in said vessel, said first tube having a first aperture of a first particular size therein and said second tube having a second aperture of a second particular size greater than said first particular size,

at least a third of said plurality of tubes at a second, lower height in said vessel, said third tube having a third aperture therein substantially larger than said first particular size of said first aperture,

first control means for controlling passage of said fluid from said vessel to said first tube,

first sensing means coupled to said second tube and said first control means for sensing the rate of particles entering said second tube from said vessel through said second aperture, said first sensing means operative in response to a reduction in the rate of particles in excess of a particular size entering said second tube to actuate said control means for allowing fluid to flow from said vessel into said first tube, and

second control means for controlling passage of said fluid from said vessel to said third tube.

10. The apparatus of claim 9 further including third control means for controlling passage of said fluid from said vessel into said second tube.

11. The apparatus of claim 9 further including second sensing means coupled to said first aperture for sensing particles entering said first tube from said vessel through said first aperture.

12. The apparatus of claim 9 further including third sensing means coupled to said third aperture for sensing particles in said fluid entering said third tube through said third aperture from said vessel.

13. The apparatus of claim 9 wherein said first sensing means includes first scanning means coupled to said second tube and operative in response to passage of particles in said fluid through said second aperture to produce an electric signal for each passing particle the value of which is related to the dimensions of the respective particles, and threshold means coupled to said first scanning means and operative in response to a reduction in the repetition rate of said electric signals in excess of a particular value to develop a control signal, said control means being coupled to said threshold means and operative in response to said control signal to allow fluid to flow from said vessel to said first tube.

14. The apparatus of claim 11 wherein said second sensing means includes second scanning means coupled to said first aperture in said first tube and operative in response to passage of particles in said fluid through said first aperture to produce an electric signal for each passing particle the value of which is related to the dimensions of the respective particle, and processing means coupled to said second scanning means and operative in response to each of said electrical signals to at least count said signals for counting the number of particles passing into said first tube.

15. The apparatus of claim 12 wherein said third sensing means includes third scanning means coupled to said third aperture in said third tube and operative in response to passage of particles in said fluid through said third aperture to produce an electric signal for each passing particle the value of which is related to the dimensions of the respective particles, and processing means coupled to said third scanning means and operative in response to said electric signals to at least count said electric signals for counting the number of particles passing into said third tube.

16. The apparatus of claim 9 further including second control means coupled to said second tube for controlling passage of said fluid from said vessel to said second tube, and third control means coupled to said third tube for controlling passage of said fluid from said vessel to said third tube.

17. The apparatus of claim 16 further including second sensing means coupled to said first aperture for sensing particles entering said first tube from said vessel, and third sensing means coupled to said third aperture for sensing particles entering said third tube from said vessel.

18. The apparatus of claim 17 wherein said first sensing means includes first scanning means coupled to said second aperture in said second tube and operative in response to passage of particles through said aperture and into said second tube to produce an electric signal for each passing particle the value of which is related to the dimensions of the respective particle, and threshold means coupled to said first scanning means and operative in response to the reduction in the repetition rate of said electric signals in excess of a particular value to develop a control signal, said control means being coupled to said threshold means and operative in response to said control signal to allow fluid to flow from said vessel to said first tube.

19. The apparatus of claim 18 wherein said second and third sensing means each include scanning means coupled to said apertures and operative in response to passage of particles through said apertures in said second and third tubes respectively to produce an electric signal for each passing particle the value of which is related to the dimensions of the respective particles, and processing means coupled to said scanning means and operative in response to each of said electric signals to at least count said particle passage.

20. An apparatus for studying particles of widely different sizes by use of the Coulter principle comprising,

a first vessel carrying a body of fluid having particles of widely varying size suspended therein,

at least first, second and third tubes suspended in said vessel and having first, second and third apertures respectively therein for enabling flow of fluid from said vessel to said tubes, said first and second tubes and apertures being at substantially the same depth in said vessel and said third tube and aperture being at a lower depth, said second and third apertures being substantially the same in size, and said first aperture being substantially smaller than said second and third apertures,

first, second and third fluid control means coupled to said apertures for causing said fluid to flow through said apertures,

means for actuating said second and third fluid control means for enabling flow of fluid through said second and third apertures,

first, second and third scanning means coupled to said first, second and third apertures respectively, said scanning means each being responsive to the passage of particles through said apertures to produce an electric signal for each passing particle, the value of which is related to the dimensions of respective particles,

threshold means coupled to said second scanning means and operative in response to the reduction in the repetition rate of said electric signals in excess of a particular value to develop a control signal, and

means for actuating said first fluid control means coupled to said threshold means and said first fluid control means and operative in response to said control signal to enable flow of fluid through said first aperture, and

pulse analysis means, coupled to said first and third scanning means for analyzing the electric signals produced thereby.

21. The apparatus of claim **20** wherein said first, second and third fluid control means includes pressure differential means coupled to said first, second and third tubes for creating a pressure differential between the interior of said tubes and the interior of said vessel for allowing said fluid to flow through said apertures.

22. The apparatus of claim **21** wherein said pressure differential means includes vacuum generation means for developing a vacuum in said first, second and third tubes.

23. The apparatus of claim **20** wherein said pulse analysis means includes counter means for counting said electric signals for determining the concentration of particles in said fluid.

24. The apparatus of claim **20** wherein said means for actuating said second and third fluid control means is a switch.

25. The apparatus of claim **20** wherein said threshold means includes integration means for developing an integration voltage, said integration means being operative in response to said electric signals coupled thereto to discharge said integration voltage, and circuit means coupled to said integration means and operative in response to said integration voltage exceeding a predetermined amplitude to develop said control signal.

26. The apparatus of claim **20** wherein said first, second and third scanning means includes particle detectors of the Coulter type.

27. The apparatus of claim **20** wherein said first, second and third scanning means each includes a first electrode positioned in said vessel and in said fluid, a second electrode positioned in each one of said first, second and third tubes, a separate scanning circuit including a current source connected to each respective electrode in said tubes, and to said common electrode, the current source serving to establish a stable constricted electrical current through said respective apertures between said vessel and each of the respective tubes, for producing an electrical pulse in said scanning circuit through whose aperture a particle passes when the particle passes therethrough.

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