

[54] **FLUID SUPPLY CONTROL METHOD AND APPARATUS FOR PERIODIC, PRECISE FLUID MERGER**

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 [51] Int. Cl. ....F17d 1/08, F16k 19/00  
 [58] Field of Search ....137/1, 154, 605; 251/4, 9; 222/4, 450, 452; 23/230 A; 356/181; 73/423 R, 423 A

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[57] **ABSTRACT**

New and improved fluid supply control method and apparatus for periodic fluid merger which are particularly adapted to the periodic, precisely timed introduction of precisely and uniformly sized fluid segments into a fluid stream are disclosed and comprise a segmenting fluid supply line which respectively connects with a pressurized source of said segmenting fluid at substantially constant pressure and with the line in which said fluid stream is flowing. First and second, quick-acting flow interrupting means are operatively associated with said fluid supply line at spaced locations thereon, and a cavity of substantially constant volume is formed between said flow interrupting means. In operation, and for the formation of each of said segments, said first flow interrupting means are opened to effect the filling of said cavity with said pressurized fluid whereupon said first flow interrupting means are closed and said second flow interrupting means opened to effect the flow of said pressurized fluid from said cavity into said fluid stream to form said segments. A form of the invention is disclosed wherein said fluid supply line is constituted by a compressible, resilient tube and said flow interrupting means comprise means to compress and close said tube at spaced locations thereon. In this disclosed form, the cavity is formed by the volume of the tube which extends between said flow interrupting means.

7 Claims, 7 Drawing Figures

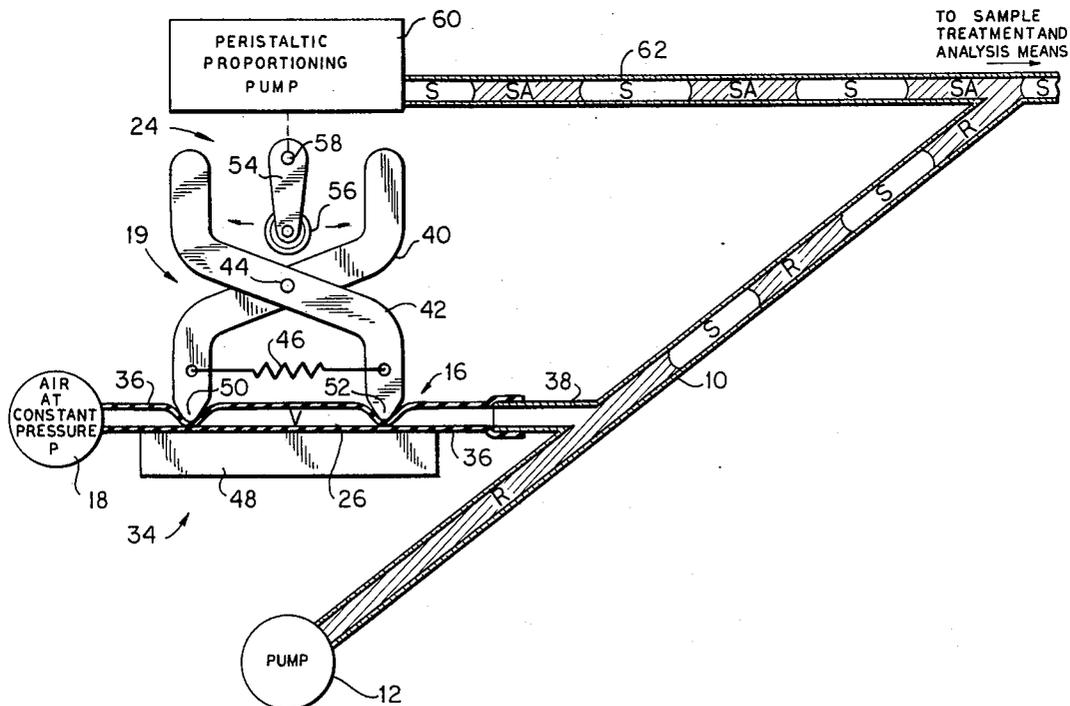


FIG. 1

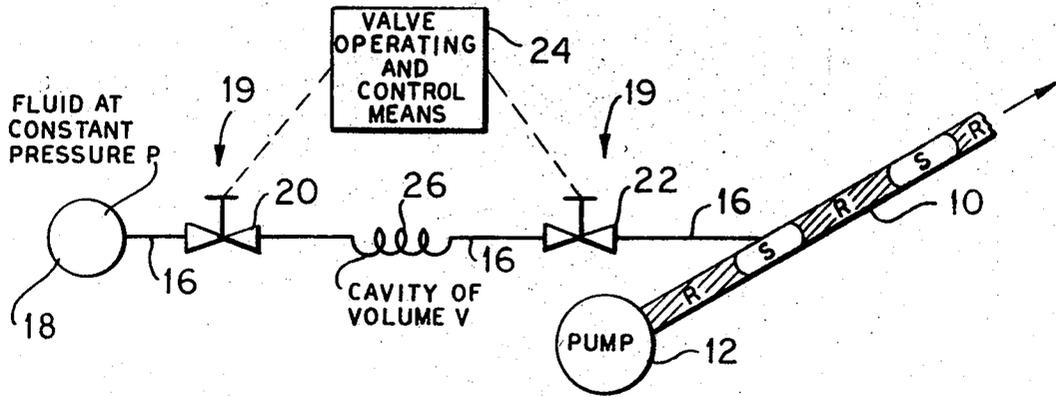


FIG. 2A

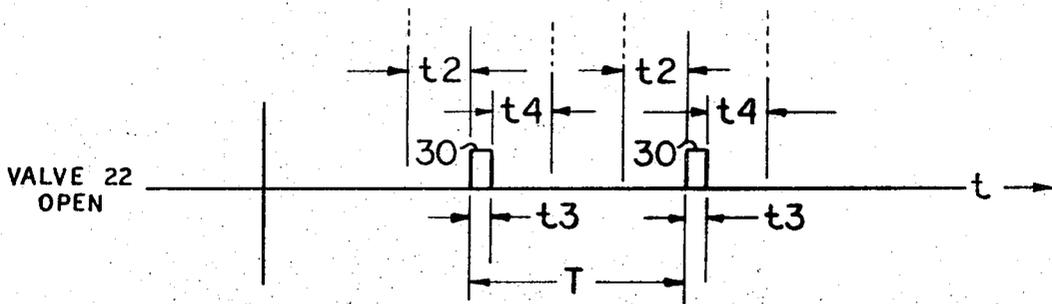
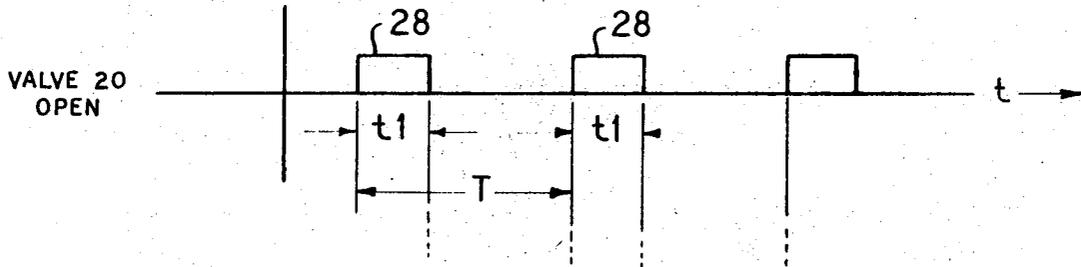


FIG. 2B

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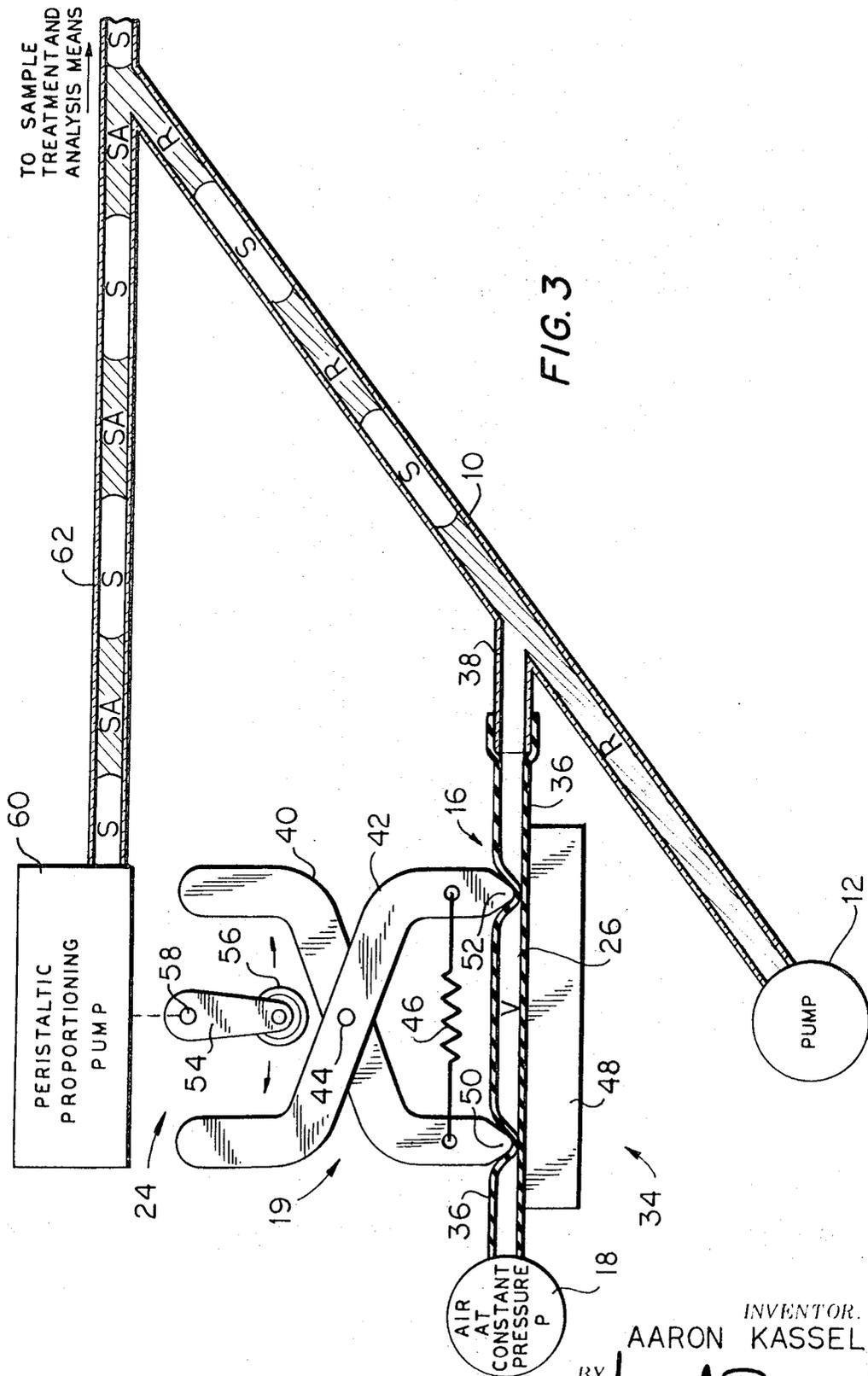


FIG. 3

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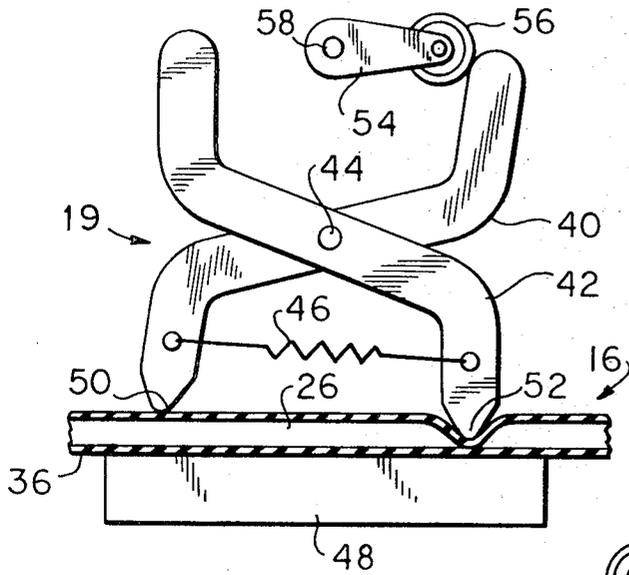


FIG. 4

FIG. 5

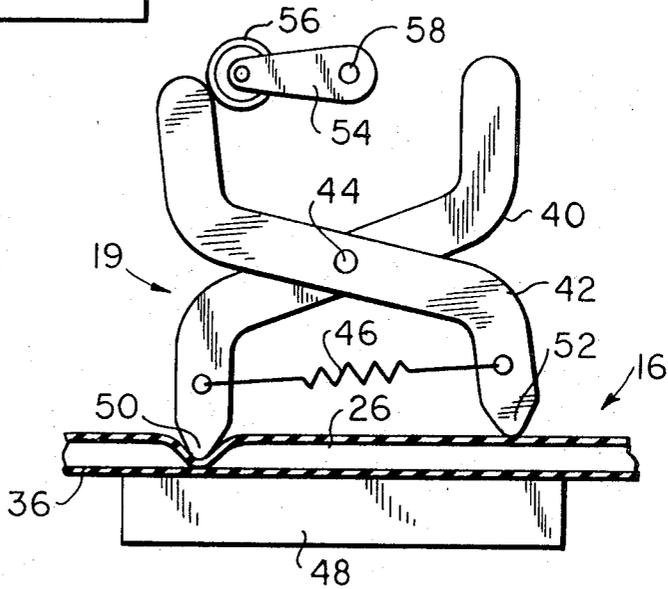
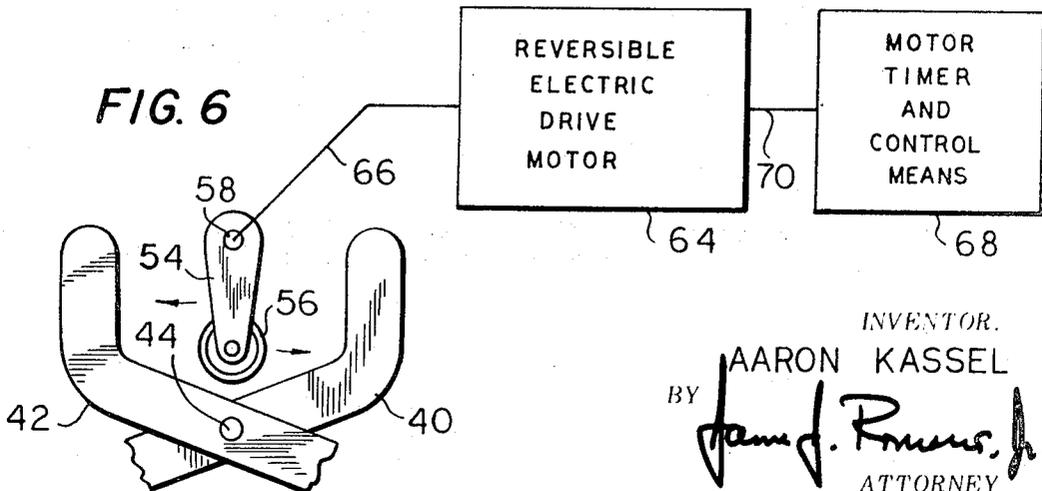


FIG. 6



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# FLUID SUPPLY CONTROL METHOD AND APPARATUS FOR PERIODIC, PRECISE FLUID MERGER

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates to new and improved fluid supply control method and apparatus for periodic precise fluid merger and, more particularly, to such method and apparatus as are particularly adapted to the periodic, precisely timed introduction of precisely and uniformly fluid segments into a fluid stream.

### 2. Description of the Prior Art

In the operation, for example, of automatic, substantially constant flow rate and continuous flow fluid sample supply, treatment and analysis apparatus of the nature disclosed in U.S. Pat. No. 3,134,263 issued May 26, 1964 to Edward B.M. DeJong and assigned to the assignee hereof, and/or U.S. Pat. No. 3,241,432 issued Mar. 22, 1966 to Dr. Leonard T. Skeggs, et al., and assigned to the assignee hereof, it may be understood that a continuous stream of fluid sample segments, as spaced by intervening segments of a separating fluid or fluids in the nature of air segments for wash and sample segment delineation purposes, is merged in substantially fixed proportion with a similarly segmented stream of a suitable color-producing reagent to effect a desired color-producing reaction and enable subsequent colorimetric analysis of said sample segments with regard to a constituent of interest thereof. Preferably, the segmentation and merger of said segmented sample and reagent streams are effected in precisely synchronized manner so that sample-reagent segment merger rather than, for example, sample stream air segment-reagent segment, or reagent stream air segment-sample segment, takes place to thus promote to the maximum possible extent the desired sample-reagent mixture with attendant like promotion of the color producing reaction of interest. Too, it is believed clear that improperly timed or imprecise air segmentation of the reagent stream may result in unacceptable variation in the desired sample-reagent mixture proportion.

In prior art apparatus of the type discussed hereinabove, the requisite air segmentation of the reagent stream is effected through the use of multiple compressible tubes of a peristaltic proportioning pump of the nature disclosed, for example, in U.S. Pat. No. 3,227,091 issued Jan. 4, 1966 to Jack Isreeli, et al., and assigned to the assignee hereof, and/or U.S. Pat. No. 3,306,229 issued Feb. 28, 1967 to William J. Smythe. Although this means of air segmenting the reagent stream of interest is satisfactory, it may be understood that the use thereof in improved versions of said automatic, substantially constant flow rate sample supply, treatment and analysis means which are operable, to significant advantage, with substantially reduced flow rates and substantially reduced sample volumes, and at substantially increased sample analysis rates, can be lead to problems which result from pump tube fatigue, due to repeated occlusion thereof over long periods of time, with attendant change in the delivery rate of said pump tubes and resultant improperly timed and/or imprecisely metered segmentation of said reagent stream.

An alternative prior art method of achieving the desired air-segmentation and supply of said reagent stream for synchronized merger with said sample stream involves the utilization of constant flow pressure pumping systems including relatively complex and expensive flow regulators of somewhat questionable reliable and which, in any event, require frequent checking and adjustment, all to significant disadvantage as should be obvious.

## OBJECTS OF THE INVENTION

It is, accordingly, an object of this invention to provide new and improved fluid supply control method and apparatus for periodic precise fluid merger which are particularly adapted to the periodic, precisely timed introduction of precisely and uniformly sized fluid segments into a fluid stream.

Another object of this invention is the provision of apparatus as above which require the use of only readily available, relatively inexpensive components of proven dependability in the fabrication thereof, and which are of basically simple construction and manner of operation, to thereby provide for relatively low apparatus costs and long periods of accurate, substantially maintenance-free apparatus operation.

A further object of this invention is the provision of method and apparatus as above which are particularly, through by no means exclusively, adapted to the precisely synchronized and metered air-segmentation of a reagent liquid stream in automatic, substantially constant flow rate fluid sample supply, treatment and analysis apparatus of the type disclosed in U.S. Pat. Nos. 3,134,263 and/or 3,241,432, respectively.

## SUMMARY OF THE INVENTION

As disclosed herein, the new and improved fluid supply control method and apparatus of the invention for the periodic, precisely timed introduction of precisely and uniformly sized fluid segments into a fluid stream comprise a fluid supply line which merges into the line in which said fluid stream is flowing.

First and second, quick-acting flow interrupting means are operatively associated with said fluid supply line at spaced or upstream and downstream points thereon, and a cavity of substantially constant volume V is provided between said flow interrupting means. A source of the fluid of interest at substantially constant pressure P is operatively associated with the inlet of said fluid supply line. Operating and control means are operatively associated with the flow interrupting means and are effective to independently operate and control the same in accordance with a precisely predetermined operational cycle.

In operation, and with both said first and second flow interrupting means initially closed, said first or upstream flow interrupting means are opened for a predetermined time to effect the filling of the cavity with the fluid of interest at the substantially constant pressure P. Following this, said first flow interrupting means are re-closed and maintained closed for a second predetermined period of time, at the expiration of which said second or downstream flow interrupting means are opened for a third predetermined period of time to enable the flow of the fluid from the cavity into the line in which said fluid stream is flowing to form a fluid segment of precisely determined size therein. Then, said second flow interrupting means are re-closed and maintained closed, along with said first flow interrupting means, for a fourth predetermined period of time, at the expiration of which the described operational cycle is repeated.

In one disclosed form of the invention, the fluid supply line takes the form of a tube of any suitably compressible and resilient material of sufficient strength characteristics in the nature, for example, of silicone rubber, while said first and second flow interrupting means take the form of a cam-operated arm assembly having first and second arms which are independently operable to compress and close said tube at spaced points thereon. In this form of the invention, the cavity of volume V is formed by the tube length which extends between said spaced points.

In another disclosed form of the invention, the flow interrupting means are formed by first and second quick-acting valve means, while the cavity may be formed therebetween in any practicable manner.

## DESCRIPTION OF THE DRAWINGS

The above and other objects and significant advantages of this invention are believed made clear by the following detailed description thereof taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic diagram of new and improved fluid supply control apparatus constructed and operative in accordance with the teachings of this invention;

FIGS. 2A and 2B are timing diagrams drawn to the same time scale and illustrating the operation of the fluid flow interrupting means of the apparatus of FIG. 1;

FIG. 3 is a partially schematic side view with parts in cross section of a form of the apparatus of FIG. 1;

FIG. 4 illustrates the fluid flow interrupting means of the apparatus of FIG. 3 in a first operative position thereof;

FIG. 5 illustrates the fluid flow interrupting means of the apparatus of FIG. 3 in a second operative position thereof; and

FIG. 6 illustrates an alternate form of fluid flow interrupting means operating and control means.

#### DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, a fluid line is indicated at 10, and pump means or the like are schematically indicated at 12 and are operatively associated as shown with line 10 to pump a stream R of fluid therethrough from a non-illustrated fluid source at substantially constant flow rate in the indication direction.

New and improved fluid supply control means constructed and operative in accordance with the teachings of this invention for the periodic, precisely timed introduction of precisely sized fluid segments S to the fluid stream R are illustrated schematically at 14, and comprise a segmenting fluid supply line 16 which merges as shown with the fluid supply line 10. A source of the segmenting fluid of interest at substantially constant pressure P is indicated schematically at 18 and is operatively connected as shown to the inlet of the fluid supply line 16 for the supply of said segmenting fluid thereto at said substantially constant pressure P. The said pressure P is, of course, sufficiently higher than the pressure at which the fluid stream R is pumped through fluid line 10 to insure flow in the indicated direction.

Quick-acting flow interrupting means 19 which may, for example, take the form of quick-acting valve means are indicated schematically at 20 and 22 and are operatively disposed as shown at spaced locations in the segmenting fluid supply line 16. Valve operating and control means are indicated schematically at 24 and are operatively associated as indicated by the dashed lines with each of the valve means 20 and 22 to effect the respective openings and closings thereof in precisely timed sequence as described in greater detail hereinbelow. A cavity of volume V is schematically indicated at 26 and is formed as shown by or in the segmenting fluid supply line 16 between the respective valve means 20 and 22.

In operation, under steady state conditions with the fluid stream R flowing through fluid line 10 at substantially constant flow rate and the segmenting fluid being supplied to supply line 16 at substantially constant pressure P, and also referring now to the valve operating timing diagrams of FIGS. 2A and 2B which are, of course, drawn to the same time scale and wherein the square waves 28 illustrate the openings of valve means 20 and the square waves 30 illustrate the openings of valve means 22, it may be seen that valve means 20 will be opened first, under the control of valve operating and control means 24, for a time  $t_1$  to effect the filling of cavity 26 with the segmenting fluid substantially at pressure P since valve means 22 remain closed. At the expiration of time  $t_1$ , valve means 20 will re-close to thus leave the cavity 26 filled with the segmenting fluid substantially at pressure P. This condition is continued for a time  $t_2$ , at the expiration of which valve means 22 are opened as indicated under the control of valve operating and control means 24 for a time  $t_3$  to thus effect the flow of the pressurized fluid from cavity 26 through said valve means and supply line 16 into the fluid stream R flowing in fluid line 10 to form a fluid segment S of the desired volume therein.

At the expiration of time  $t_3$ , valve means 22 are re-closed and maintained closed to thus complete an operational cycle of the fluid supply control means 14 of the invention and effect the formation of a segment S in the fluid stream R.

At the expiration of time  $t_4$ , the succeeding cycle of the fluid supply control means 14 of the invention is commenced as indicated to form the succeeding segment S in the fluid stream R by the re-opening of the valve means 20 for a time  $t_1$ . Said succeeding cycle is completed by the subsequent re-closure as indicated of the valve means 20 for a time  $t_2$ , the opening of valve means 22 for a time  $t_3$ , and the re-closure of the latter, respectively.

The total time T which elapses between each opening of the valve means 20 is made equal as indicated to the total time T which elapses between each opening of the valve means 22, while the frequency of segment formation in the fluid stream R is equal to  $1/T$  and may thus be precisely controlled as desired through control of the time T. Too, the combined elapsed times  $t_4 + t_1 + t_2$  in that order between the closing and opening of the valve means 22 may, when determined in relationship to the substantially constant velocity of flow of the fluid stream R in line 10, be utilized to precisely control the spacing of the fluid segments S in said fluid stream.

The size of the respective segments S in the fluid stream R may be precisely determined through proper choice of the fluid pressure P and the volume V of cavity 26, whereby may be understood that the respective times  $t_1$  and  $t_3$  that the valve means 20 and 22 are maintained open will be rendered substantially non-critical in this regard within reasonable limits.

Precise uniformity in size and spacing of the respective fluid segments are respectively achieved through the maintenance of the pressure P and cavity volume V at substantially constant values, and through the maintenance of the combined elapsed times  $t_4 + t_1 + t_2$  substantially constant.

A form of the new and improved fluid supply control means for use in the precisely timed segmentation of a color-producing reagent liquid stream by the introduction of precisely and uniformly sized air segments thereto is indicated generally at 34 in FIG. 3, and is again operatively associated with a fluid line 10 which, in this instance, takes the form of a reagent supply line. Reagent liquid pump means are again schematically indicated at 12 and are, of course, operative to pump a stream of said reagent liquid from a non-illustrated source thereof through said reagent supply line at substantially constant flow rate.

The segmenting fluid supply line as generally indicated at 16 here takes the form of a tube 36 of any inert, readily compressible material of suitable resiliency and strength characteristics in the nature, for example, of silicone rubber. Since, in this instance, the segmenting fluid is air, it may be understood that the segmenting fluid source, as again indicated schematically at 18, would, of course, be a suitable source of air at substantially constant pressure P in the range, for example, of 5 to 8 psi. The operative connection of the air supply tube 36 to the reagent liquid line 10 is preferably effected as illustrated by the simple extension of an air inlet nipple 38 from the latter and the stretching of the end of said tube thereover to form a fluid-tight connection therebetween.

Referring now to the quick-acting flow interrupting means 19, the same may be seen to comprise generally "S" shaped arms 40 and 42 which are respectively pivotally supported as indicated from common pivot means 44. A tension spring 46 is provided to extend as shown between the respective lower arm portions to return the same to the respective illustrated positions thereof.

A platen is indicated at 48 and is operative to support the lower surface portion of the tube 36 and prevent downward movement thereof.

The arms 40 and 42 respectively comprise generally rounded lower extremities as indicated at 50 and 52, each of which is operative when in the depicted position thereof to compress the adjacent portion of the compressible tube 36 as shown against the upper surface of the platen 48 to close said tube portion and prevent fluid flow therethrough. The cavity 26 of volume V is, of course, formed as indicated by the volume of the length of the tube 36 which extends between the closed portions thereof.

Referring now to the valve operating and control means 24, the same are constituted in part by a cam 54 having a cam roller 56 supported for rotation as shown from the lower portion thereof. The cam 54 is, in turn, fixedly attached to a cam shaft 58 which is drivable as indicated in both directions to drive the cam 54 between first and second operative positions thereof. More specifically, and with cam 54 driven to the first operative position thereof as seen in FIG. 4, the generally rounded end 50 of arm 40 will be raised from occluding contact with the relevant portion of tube 36 to thus enable fluid flow therethrough. Alternatively, with cam 54 driven to the second operative position thereof as seen in FIG. 5, the generally rounded end of arm 42 will be raised from occluding contact with the relevant portion of the tube 36 to likewise enable fluid flow therethrough.

The fluid supply control means 34 of FIG. 3 are particularly adaptable for use in the air-segmentation of a reagent liquid stream in automatic, substantially constant flow rate liquid sample supply, treatment and analysis apparatus of the nature disclosed, for example, in U.S. Pat. Nos. 3,134,263 and 3,241,432. Each of these apparatus comprises a peristaltic proportioning pump of the nature disclosed in somewhat greater detail, for example, in U.S. Pat. No. 3,277,091, which functions to provide a continuous supply of an air-segmented liquid sample stream for sample treatment and analysis. In such apparatus the respective air-segmented liquid sample and reagent streams are merged to effect a desired color-producing reaction, and it may be understood that such merger is preferably synchronized to insure liquid sample segment-reagent segment merger rather than, for example, air segment-reagent segment or air segment-liquid sample segment merger. Too, it may readily be understood to be of significant import that the proportion in which said liquid sample and reagent streams are mixed be maintained substantially constant, and that improperly timed or imprecisely metered segmentation of said reagent stream can, of course, result in unacceptable variation in said proportion.

Peristaltic proportioning pumps of the nature disclosed in said United States Patents may be understood to be operable through the concomitant and progressive occlusion of two or more compressible pump tubes by a plurality of moveable pump rollers to concomitantly pump fluids therethrough at substantially the same constant flow velocity, and it is believed clear that synchronization of the operation of the fluid supply control means 34 of FIG. 3 with the operation of said pump rollers will be effective to achieve the desired synchronization of the respective air-segmented liquid sample and reagent liquid streams.

More specifically, and referring again to FIG. 3, a peristaltic proportioning pump of the type discussed hereinabove is indicated schematically at 60 and may be understood to be operative to supply an air-segmented liquid sample stream, comprising alternating liquid sample segments SA and air segments S, through conduit 62 for merger as indicated with the air-segmented reagent stream R. A dashed line extends from the proportioning pump 60 to the cam shaft 58 and indicates the drive of the latter to move the cam 54 between the first and second positions thereof as respectively illustrated in FIGS. 4 and 5 in substantial synchronism with the movement of the non-illustrated pump rollers.

In operation for the system application illustrated in FIG. 3, and assuming steady state operational conditions to have been reached, it may be understood that an operational cycle of the fluid supply control means 34 of the invention will be commenced by the drive of the cam 54 to the first position thereof as depicted in FIG. 4 for the time  $t_1$  of FIG. 2A to lift end portion 50 of arm 40 to open the relevant portion of the tube 36 and enable the filling of cavity 26 with pressurized air at substantially the constant pressure P, it being understood that the strength characteristics or resistance to expansion of any significance of the tube 36 are, of course, chosen to substantially preclude any expansion of the volume V in response to the pressurization thereof as described. Thus the volume V is maintained substantially constant as desired and fatigue of the

tube as would accompany repeated stretching thereof also substantially precluded.

At the expiration of time  $t_1$ , cam 54 is returned to the inoperative or central position thereof of FIG. 3, whereby tension spring 46 will return arm 40 to the position thereof depicted in said FIG. to re-close the relevant portion of tube 36 and effect the entrapment of the volume V of air at substantially the pressure P in the cavity 26.

At the subsequent expiration of time  $t_2$  of FIG. 2B, the cam 54 will be driven to the second position thereof as illustrated in FIG. 5 for the time  $t_3$  to raise the end portion of arm 42 to open the relevant portion of the tube 36 and enable the flow of the pressurized air from the cavity 26 through the downstream portion of tube 36, into and through the inlet nipple 38, into the reagent liquid stream R flowing in reagent supply line 10 to thus form the air segment S precisely of the desired size therein.

At the subsequent expiration of time  $t_4$  of FIG. 2B, cam 54 is returned to the inoperative or central position thereof of FIG. 3 whereby tension spring 46 will return arm 42 to the position thereof depicted in said FIG. to re-close the relevant tube portion and complete one air-segment introduction cycle of operation. Operation of the fluid supply control means 34 is, of course, automatically continuous as described.

An alternate form of drive means for driving cam shaft 58, and accordingly cam 54, between the first and second operative positions of the latter is schematically illustrated in FIG. 6 and comprises a readily reversible electric drive motor 64 which is drivingly connected as indicated by line 66 to the cam shaft 58 so as to drive the same as described. Motor timer and control means are schematically indicated at 68 and are operatively connected as shown to drive motor 64 by line 70 to control the operation thereof in precise accordance with a desired operational sequence. A wide variety of still other and different cam shaft drive means will readily occur to those skilled in this art.

Proper choice as described of the material from which the tube 36 is made will provide for high resistance to fatigue thereof for long operational periods despite the repeated opening and closure of the effective tube portions by the arm members 40 and 42. The fatiguing effects of such repeated tube openings and closures over long period of time can, in any event, be substantially reduced by the simple expedient of periodically shifting the tube 36 longitudinally relative to the platen 48 and arm members 40 and 42 to thereby periodically expose different tube portions to said repeated openings and closures.

Although disclosed hereinabove by way of illustration as applied to the precise control of the supply of a segmenting fluid to segment another fluid stream, it is clear that the new and improved fluid supply control method and apparatus of the invention are by no means limited to such application, but rather, may be utilized with equally significant advantage in a very wide variety of applications other and different than stream segmentation applications wherein the periodic and precisely timed merger of two fluids in precisely predetermined proportion is desired. Too, the method and apparatus may, in any event, be alternatively utilized, for example, to periodically merge a liquid with a liquid, a liquid with a gas, or a gas with a gas.

While I have shown and described the preferred embodiment of my invention, it will be understood that the invention may be embodied otherwise than as herein specifically illustrated or described, and that certain changes in the form and arrangement of parts and in the specific manner of practicing the invention may be made without departing from the underlying idea or principles of this invention within the scope of the appended claims.

What is claimed is:

1. In fluid supply control apparatus for the introduction of a fluid into a fluid stream, the improvements comprising, a fluid supply line of compressible resilient material and having the outlet thereof operatively connected with the line in which

said fluid stream is flowing, a pressurized source of the fluid to be introduced, said source being operatively connected with the inlet of said fluid supply line, first and second flow interrupting means operatively associated with said fluid supply line at spaced points thereon, said first flow interrupting means being located between said fluid source and said second flow interrupting means, a cavity of substantially constant volume formed between said first and second flow interrupting means, and means to operate said flow interrupting means to open said first flow interrupting means to enable the filling of said cavity with fluid from said source, to then re-close said first flow interrupting means and open said second flow interrupting means to enable the flow of said fluid from said cavity for introduction into said fluid stream, and to then re-close said second flow interrupting means, said first and second flow interrupting means comprising first and second arm members, respectively, which are independently and pivotally moveable between a first or operative position to compress and close said fluid supply line and a second or inoperative position to release and open said fluid supply line.

2. In apparatus as in claim 1 wherein, said flow interrupting

means comprise biasing means operatively connected to said first and second arm members and operable to bias the same to the respective operative positions thereof.

3. In apparatus as in claim 2 wherein, said flow interrupting means operating means comprise cam means operatively associated with said first and second arm members and operable to drive the same to said inoperative positions thereof.

4. In apparatus as in claim 3 wherein, said cavity is formed by the volume of the length of said tube which extends between said spaced tube locations.

5. In apparatus as in claim 4 wherein, said material is silicone rubber.

6. In apparatus as in claim 1 wherein, said flow interrupting means operating means comprise cam means operatively associated with said first and second arm members and operable to drive the same to said inoperative positions thereof.

7. In apparatus as in claim 1 wherein, said cavity is formed by the volume of the length of said tube which extends between said spaced tube locations.

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