United States Patent

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[54] METHOD AND APPARATUS FOR THE PUMPING OF FLUIDS AT SUBSTANTIALLY CONSTANT FLOW RATE

13 Claims, 3 Drawing Figs.

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[51] Int. Cl. F04b 51/00
[50] Field of Search 103/148, 149; 230/168, 160; 91/57; 417/53, 477

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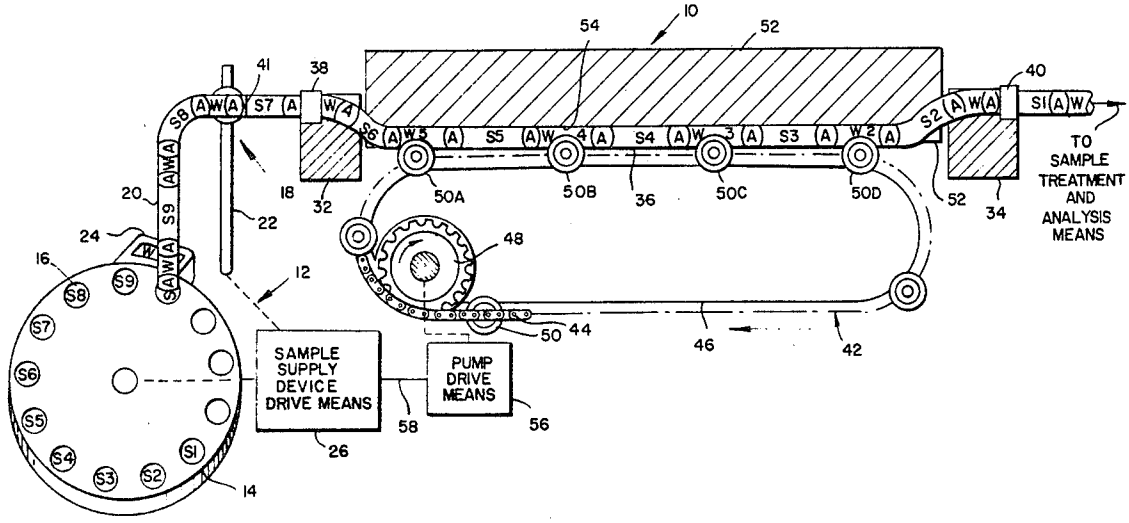
ABSTRACT: New and improved method and apparatus for the pumping of fluids at substantially constant flow rate are provided and comprise the use of compressible tube pump means which are operable to pump a stream of a series of fluid sample portions spaced, each from the other, by a separating fluid portion, through a compressible pump tube by the concomitant, progressive occlusion of said pump tube by a plurality of substantially equally spaced pump rollers only at locations on the former corresponding to the locations therein of some, at least, of said separating fluid portions whereby one or more of said fluid sample portions will be located in said pump tube entirely between said occluded locations thereon to provide for a substantially constant pump delivery, sample portion flow rate.



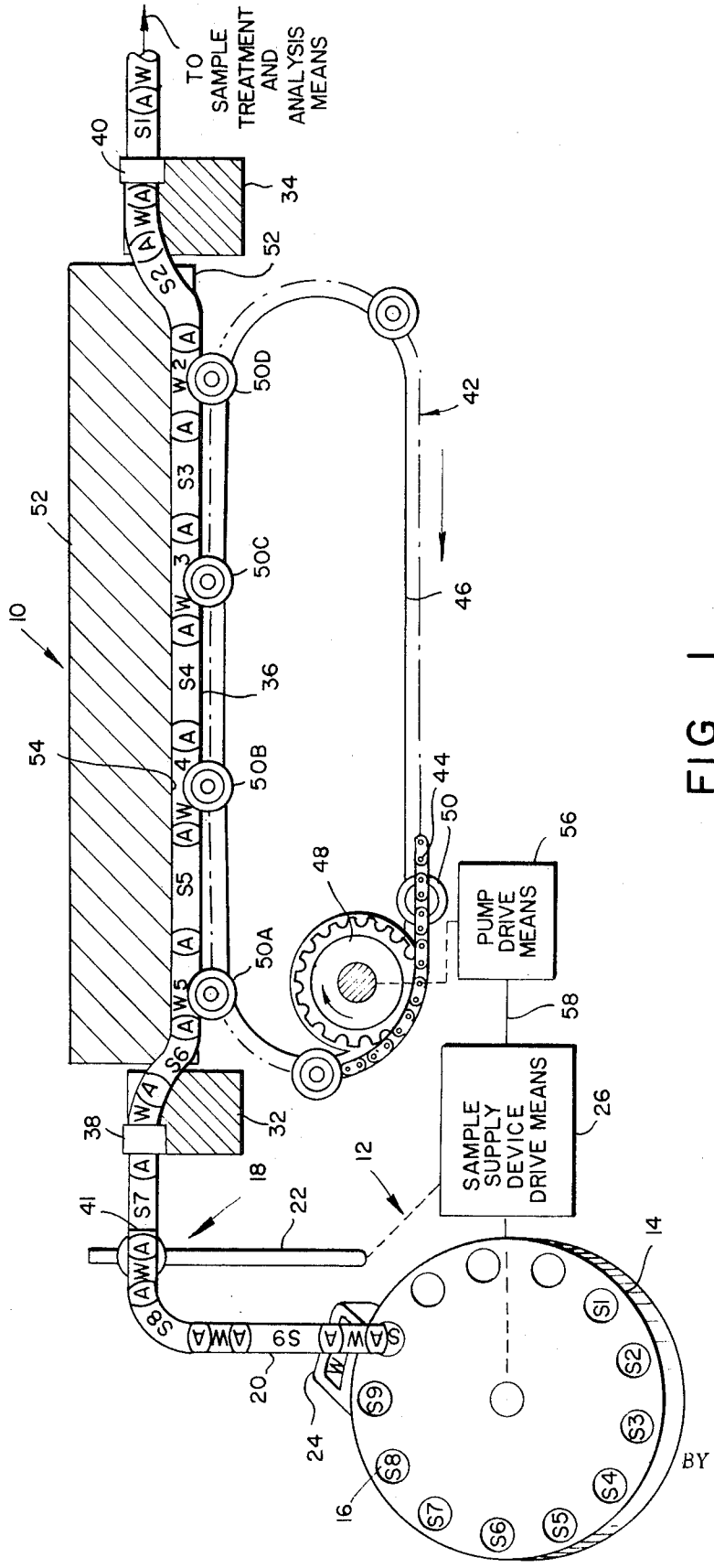


FIG. 1

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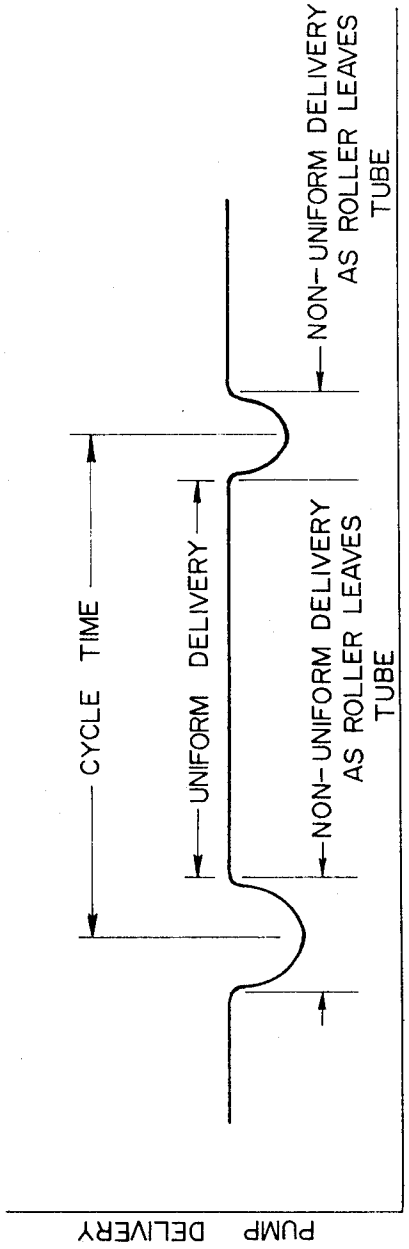

FIG. 2

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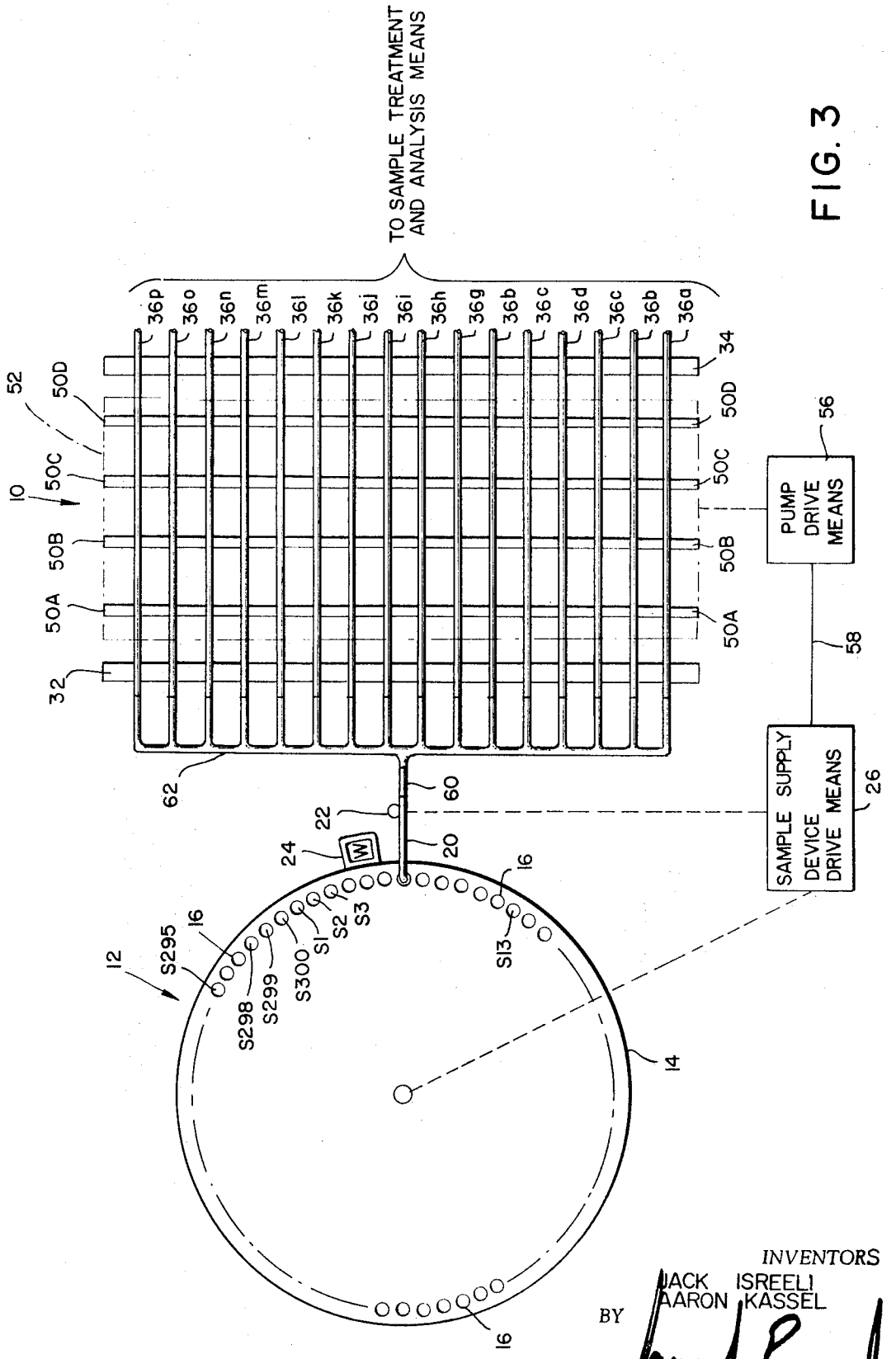

FIG. 3

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METHOD AND APPARATUS FOR THE PUMPING OF FLUIDS AT SUBSTANTIALLY CONSTANT FLOW RATE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a new and improved method and apparatus for the pumping of fluids at accurate and uniform flow rates.

2. Description of the Prior Art

Although fluid pump means in the nature, for example, of those shown and described in U.S. Pat. No. 3,227,091 issued Jan. 4, 1966 to Jack Isreeli et al., and U.S. Pat. No. 3,353,567 issued Nov. 21, 1967 to Jack Isreeli, are known for the supply of fluid samples to substantially constant flow rate, fluid sample treatment and analysis means in the nature, for example, of those shown and described in U.S. Pat. No. 3,241,432, it may be understood that said fluid pump means, operable as described, are generally unsuitable for use with new and improved versions of said fluid sample treatment and analysis means which are operable, to significant advantage, with substantially reduced sample volumes, and at substantially reduced constant sample flow rates, and substantially increased sample per unit time analysis rate, respectively.

More specifically, it may be understood that said fluid pump means which comprises one or more compressible pump tubes and are operable to pump a series of fluid samples therethrough by the repeated, longitudinally progressive compression or occlusion of said pump tubes by a series of spaced pump rollers, embody an inherent variation in the pump delivery rate as caused by a pulsation which occurs every time one of said pump rollers discontinues occluding contact with said compressible pump tube. Since, in a typical application, said fluid pump means require, for example 30 pump tube-occluding contacts by said rollers with said compressible pump tube, and accordingly 30 discontinuations in such contacts, for the pumping of each of said fluid samples, it may be understood that 30 of said pulsations will occur for the pumping of each said fluid samples with resultant adverse effect upon the requisite, substantially constant sample flow rate. If said fluid sample is of sufficient volume, however, and the sample slow rate of sufficient magnitude, the overall effect of said pulsations upon the requisite, substantially constant fluid sample flow rate is tolerable. If, on the other hand, the volume of said fluid sample is materially reduced, and the fluid sample flow rate reduced accordingly, while the sample per unit time analysis rate is substantially increased, as in the case with said new and improved versions of said fluid sample treatment and analysis means as discussed hereinabove, it may be understood that the overall effect of said pulsations upon the requisite, substantially constant fluid sample flow rate becomes intolerable.

Too, it is believed clear that the operation of said prior art pump means at a rate sufficient to provide 30 occluding contacts by said pump rollers with said compressible pump tube for each fluid sample to be pumped, can result in substantial wear on said compressible pump tube and the other components of said pump means with resultant decrease in the useful life and/or reliability thereof.

OBJECTS OF THE INVENTION

It is, accordingly, an object of this invention to provide new and improved method and apparatus for the pumping of fluid samples at accurate, substantially constant fluid sample flow rate.

Another object of this invention is the provision of method and apparatus as above which are operable to provide said accurate, substantially constant fluid sample flow rate despite substantial decrease in the latter as compared to the fluid sample flow rates provided by similar pumping apparatus of the prior art.

Another object of this invention is the provision of method and apparatus as above which make possible substantial decrease in the rate at which said apparatus must be operated to provide a desired fluid sample per unit time pumping rate to thus substantially increase the useful life and reliability of said apparatus.

A further object of this invention is the provision of apparatus as above which require the use of only readily available components of proven dependability in the fabrication thereof to insure long periods of satisfactory, maintenance-free apparatus operation.

A still further object of this invention is the provision of method and apparatus as above which are particularly adaptable for use in new and improved, reduced fluid sample volume and flow rate, and increased fluid sample analysis rate, versions of fluid sample treatment and analysis means in the nature of those shown and described in U.S. Pat. No. 3,241,432.

SUMMARY OF THE INVENTION

As disclosed herein, the method and apparatus of this invention are embodied by a compressible tube pump which is operatively associated associated with fluid sample supply means and is operable to pump a stream of a series of fluid sample portions, spaced each from the other by a separating fluid portion, through the said pump at substantially constant flow rate. More specifically, said pump comprises a plurality of substantially equally spaced pump rollers which are operative to concomitantly progressively occlude the compressible pump tube longitudinally thereof, and said sample supply means and said pump are arranged so that said pump tube is occluded by said pump rollers only at locations thereon corresponding to the locations therein of some, at least, of said separating fluid portions, whereby one or more of said fluid sample portions will be located in said pump tube entirely between said occluded pump tube locations to significantly reduce the effect of inherent operational pump pulsations upon pump flow rate and provide for the substantial accuracy and uniformity of the latter.

BRIEF 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 view in the nature of a side elevational view, with parts in cross section and parts in perspective, illustrating the method and apparatus of the invention;

FIG. 2 is a plot of pump delivery versus time of the apparatus of FIG. 1; and

FIG. 3 is a generally schematic flow diagram of the method and apparatus of the invention as applied to new and improved versions of the fluid sample treatment and analysis means of the nature disclosed in U.S. Pat. No. 3,241,432.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, new and improved compressible tube pump means constructed and operative in accordance with the method and apparatus teachings of this invention are indicated generally at **10** and are depicted in operative relationship with sample supply means as indicated generally at **12**.

The sample supply means **12** may, for example, take the form of those shown and described in U.S. Pat. No. 3,134,263 issued May 26, 1964 to Edward B. M. DeJong, and comprise a turntable **14** upon which is disposed a generally circular array of sample containers **16**. A sample offtake device is indicated at **18** and comprises a sample offtake tube **20** and offtake tube operating means **22**, respectively. A wash liquid receptacle **24** is disposed as shown adjacent the turntable **14**, while sample supply device drive means are indicated at **26** and are operative to drive each of the turntable **14** and the sample offtake device **18** as indicated by the dashed lines extending therebetween.

In operation, the turntable **14** is intermittently rotated, or indexed, to present each of the sample containers **16** to the

sample offtake device 18, while the latter is in turn operated to immerse the inlet end of offtake tube 20 in a thusly presented sample container for a predetermined period of time to aspirate (as described in detail hereinbelow) a measured volume of the sample therefrom, to then transfer the said offtake tube inlet end through the ambient air for immersion in the wash liquid receptacle for a predetermined period of time to thus aspirate a measured volume of ambient air followed by a measured volume of said wash liquid, and to then again transfer the said offtake tube inlet end through the ambient air for immersion in the next presented sample container 16 for a predetermined period of time to thus aspirate another measured volume of ambient air and commence the aspiration of a measured volume of the sample from said next said presented sample container.

As a result, it may be understood that a stream consisting of successive ones of said samples as spaced, in each instance, by a segment of air A, a segment of wash liquid W and a segment of air A, respectively, will be supplied to the offtake tube 20.

The compressible tube or peristaltic pump 10 may, for example, take the general form of that shown and described in U.S. Pat. No. 3,227,091 issued Jan. 4, 1966 to Jack Isreeli et al., and comprises spaced pump tube mounting blocks as indicated at 32 and 34.

A compressible pump tube 36, which is made from any suitably resilient material of appropriate strength characteristics in the nature, for example, of silicone rubber, is extended as shown between the said pump tube mounting blocks and affixed thereto by means of the placement of said pump tube in nonillustrated complementally shaped aligned mounting grooves formed in said pump tube mounting blocks, and the attachment of adjustably positionable collar elements 38 and 40, as shown to opposite end portions of said pump tube, all in a manner made clear in U.S. Pat. No. 3,227,091. The inlet end of the compressible pump tube 36 is connected as indicated at 41 to the outlet end of the sample offtake tube 20.

A pump roller assembly is indicated generally at 42 and comprises an endless chain 44 which is disposed as shown around a chain guide member 46 and is driveable therearound in the indicated clockwise direction through the driven rotation of a chain drive sprocket 48.

A plurality of substantially equally spaced pump rollers 50 are rotatably mounted in any convenient manner on endless chain 44 as shown, whereby may be understood that those of said rollers which are, at any given point in time, mounted on the upper throw of the endless chain 44 will be movable with the latter in the direction from left to right as seen in FIG. 1. Although for simplicity of illustration only one chain and drive sprocket are depicted, it may be understood that at least two of the same would be provided in spaced, general alignment, and that the respective pump rollers would, of course, extend therebetween.

A pump platen is indicated at 52 and may be understood to be movable from a nonillustrated "open" position thereof to the depicted "closed" position thereof wherein the pump tube 36 will be disposed within a nonillustrated, complementally shaped groove formed in the undersurface of said platen, and will be forced to conform with the configuration of the bottom surface 54 of said groove and pressed thereby against the respective relevant rollers 50, all again as described in detail in said U.S. Pat. No. 3,227,091.

Pump drive means which may, for example, take the form of any suitable electric motor, are indicated at 56, and are operatively connected, as indicated by the dashed line, to the chain drive sprocket 48 to drivingly rotate the latter. In addition, and for reasons described in detail hereinbelow, the operation of sample supply device drive means 26 is synchronized with the operation of the pump drive means 56, and this may be understood to be indicated in the drawings by the extension of lead 58 therebetween. Alternatively, it is believed clear that a single drive means in the nature of a suitable electric drive motor may be provided and operatively connected, as by conventional mechanical connecting means, to both the pump 10 and the sample supply device 12 to drive the same in the described synchronized manner.

With the respective pump components arranged and operative as described, it may be understood that driven, clockwise rotation of the chain drive sprocket 48 will effect movement of the rollers 50 affixed to the upper throw of endless chain 44 from left to right as seen in FIG. 1 with the result that the compressible pump tube 36 will be progressively compressed or occluded thereby in said direction to in turn pump fluids therethrough. For reasons described in detail hereinbelow, it may be understood that the compressible pump tube 10 and the sample supply device 12—or, more specifically, the respective drive means therefore—are arranged so that the arrival of each pump roller 50 at the position thereof wherein occlusion of the compressible tube 36 is commenced thereby, will substantially coincide with the arrival of a wash liquid segment W at the corresponding position in said pump tube.

OPERATION

In operation for use, for example, in the pumping of a stream of successive fluid samples in the nature of blood serum samples to automatic, sequentially operable blood sample treatment and analysis means of the type disclosed in U.S. Pat. No. 3,241,432 issued Mar. 22, 1966 to Leonard T. Skeggs, it may be understood that each of the sample containers 16 would be filled with a different blood serum sample, while the outlet end of the compressible pump tube 36 would be connected as indicated to the said sample treatment and analysis means.

In addition, and for reasons made clearer hereinbelow, it may be understood that if the internal diameters of the respective compressible pump tube 36 and the sample offtake tube 20, and accordingly the respective flow rates therethrough, are made substantially the same, the combined length thereof upstream of the location at which a pump roller first effectively contacts—that is to say commences to occlude—the compressible pump tube, which location is indicated by the depicted position of pump roller 50A, must, of necessity, be a multiple of the spacing between said pump rollers. Alternatively, if said internal diameters are not substantially the same, it may be understood that said combined length would, of necessity, be chosen to provide for the desired coincidence between the arrival of each wash liquid segment W at the W5 wash liquid segment position, and each of the pump rollers 50 at the 50A pump roller position.

Assuming steady state operational conditions to have been reached, it may be understood that the arrival of a wash liquid segment at the location in compressible pump tube 36 indicated by the depicted W5 wash liquid segment position will substantially coincide with the arrival of a pump roller 50 at the 50A pump roller position to commence the occlusion thereby of the said pump tube.

Movement of this leading or downstream pump roller through the 50B pump roller position, and the concomitant movement of the succeeding, trailing or upstream pump roller through the 50A pump roller position will result in an entire sample portion being flowed through the S5 sample portion position between the said leading and trailing pump rollers, with the latter respectively functioning to substantially occlude, and commencing to occlude, the respective portions of the compressible pump tube 36 through which are flowing the respective wash liquid segments as now indicated at W4 and W5.

Continued operation of the pump 10 will then result in the said pump rollers moving respectively through the 50C and 50B portions thereof, whereby the sample portion will be flowed through the depicted S4 sample portion position with the compressible pump tube 36 substantially occluded to both the downstream and upstream sides thereof by the substantial occlusion of the pump tube portions through which are flowing the respective wash liquid segments as now indicated at W3 and W4.

Subsequently, the said pump rollers will respectively move through the 50D and 50C pump roller positions, whereby the said sample portion, as still disposed therebetween, will be flowed through the depicted S3 sample portion position, and the leading or downstream roller will commence as indicated to discontinue occluding contact with the portion of the compressible pump tube 36 through which is flowing the leading or upstream wash liquid segment as now indicated at W2.

Thereafter, as the trailing or upstream pump roller moves through the 50D roller position, it may be understood that the said sample portion will be flowed through the S2 sample portion position for subsequent flow through the S1 sample portion position, and flow as indicated to the nonillustrated, operatively connected sample treatment and analysis means upon exit from the compressible pump tube 36.

Operation as described of the compressible tube pump 10 and the sample supply device 12 is, of course, continuous and will result in the supply as depicted of a series of fluid sample portions from the respective sample containers 16 to the nonillustrated, operatively connected sample treatment and analysis means, with said sample portions being spaced as depicted, each from the other, by an intervening segment of air A, wash liquid W, and air A, respectively.

Of particular significance here, however, is the fact that said sample portions will be supplied to said sample treatment and analysis means at particularly accurate and consistent or uniform flow rate. More specifically, and referring to the plot of pump delivery versus time of FIG. 2, it may be understood that through the use of means in the nature of relatively large sprocket and chain drives, small tooth gear drives or tape drives in the construction of the compressible tube pump 10 to substantially reduce pump pulsations due to nonlinear pump drive to zero, it becomes possible to provide for substantially uniform pump delivery, as indicated, during 85 percent to 90 percent of each pump cycle time, with the only significant pulsations or variations therein occuring, as indicated, when a pump roller is leaving or discontinuing contact with the compressible pump tube as would occur, for example, during the passage of said pump roller through the 50D pump roller position of FIG. 1. Accordingly, it is believed made clear that by arranging, as disclosed in detail hereinabove, to maintain each sample portion between adjacent pump rollers to utilize only that 85 percent to 90 percent substantially uniform delivery part of each pump cycle to pump a sample portion, the provision of a particularly accurate and consistent or uniform sample portion flow rate is made possible, despite the fact that such sample portion flow rate may be appreciably lower than those heretofore utilized in sample treatment and analysis means of the nature under discussion.

Of additional significance is believed the face that the method and apparatus of the invention reduce the number of times that the compressible pump tube is struck and compressed by a pump roller to one per sample portion as opposed, for example, to 30 times per sample portion for the compressible tube pumps of the prior art, whereby is believed made clear that the useful life and reliability of the compressible pump tube, and accordingly of the pump, is very significantly extended. Also, if the method and apparatus of this invention, and the compressible tube pumps of the prior art, are viewed from the standpoint of use with compressible pump tubes of the same internal diameters to provide the same sample portion flow rate, it is believed clear that the method and apparatus of this invention will make possible the operation of the compressible tube pump at very significant reduced rate, or pump roller speed, to further significantly prolong the useful life and reliability of the said pump.

A representative application of the method and apparatus of the invention to new and improved versions of the sample treatment and analysis means as shown and described in said U.S. Pat. No. 3,241,432 is illustrated in FIG. 3. As seen therein, 300 sample containers, each containing a relatively small volume of an undiluted blood serum sample, are provided on a turntable 14 of the sample supply means 12, while each of the sample supplied therefrom is flowed from the outlet end of offtake tube 20, through a readily bendable connecting conduit 60, to the inlet of sample portion splitting manifold means 62 which may, for example, take the form of those shown and described in our copending application for Ser. No. 872,816, filed Oct. 31, 1969, and assigned to the assignee hereof. As depicted, the manifold means 62 will be effective to split each sample portion into 16 subportions or quotients and, through the provision of 16 compressible pump tubes 36*a* through 36*p*, inclusive, and the connection as illustrated of the inlet of each of said compressible pump tubes to an outlet of said manifold means, simultaneously flow said sample quotients in substantially perfect phase relationship through said pump tubes for subsequent flow as indicated to nonillustrated, operatively connected sample treatment and analysis means.

For use, for example, at an extremely high sample portion pumping, treatment and analysis rate of 300 sample portions per hour, or one sample portion every 12 seconds, as compared to the sample analysis rate of 60 per hour of present analysis means, and at an extremely low sample portion flow rate in the neighborhood of 0.04 ml./min., as compared, for example, with present analysis means flow rates of 0.40 ml./min., it may be understood that pump drive means 56 would be arranged to operate compressible pump tube 10 to pump 300 sample portion quotients through each of said compressible pump tubes 16*a* through 16*p*, inclusive, per hour, while sample supply device drive means would be synchronized therewith to supply 300 sample portions per hour to the inlet of manifold means 62.

Further, with each of said sample portion quotients to be located entirely between adjacent pump rollers in each of said compressible pump tubes, and said pump rollers spaced, for example, 2 inches apart, it becomes possible to drive pump 10 only at the extremely low rate required to provide for 2 inches of pump roller movement longitudinally of said compressible pump tubes per 12 second interval, as compared, for example, to the 10 inches of such roller movement required in the said 12 second interval by present analysis means.

Various changes may, of course, be made in the method and apparatus of the invention without departing from the spirit and scope thereof as defined in the appended claims. More specifically, it may be understood that although disclosed as comprising the occlusion of the compressible pump tube 36 at a location thereon corresponding to the location of each of the wash liquid segments W therein, it may be understood that the method and apparatus of the invention would also be applicable for operation wherein said compressible pump tube would be occluded at a location thereon corresponding to the location therein of only every other one of said wash liquid segments, or every third or fourth one thereof, whereby two, three, or four of the sample portions would be maintained entirely between adjacent pump rollers to thus further reduce the effect of each pump delivery rate pulsation upon the overall sample portion flow rate.

Too, the method and apparatus of the invention would be applicable for use in instances wherein no wash liquid segments W, but rather, only air segments A were provided between sample portion, in which instances the respective pump rollers would be effective to occlude the compressible pump tube or tubes at locations thereon coinciding with the locations therein of said air segments A to, in any event, maintain one or more of said sample portions between adjacent of said pump rollers. Alternatively, if only wash liquid segments W are provided between sample portions, it is believed clear that the locations of said pump tube occlusions would, of course, coincide with the locations in said pump tube of said wash liquid segments. Also, if a continuous sample portion stream, that is to say one in which no segmenting fluids are utilized, is supplied to the compressible tube pump, it may be understood that the latter would be arranged to occlude the pump tube at locations thereon substantially corresponding to the locations therein of the respective downstream and up-

stream ends of one or more of said sample portions, whereby the latter would still be maintained substantially entirely between adjacent pump rollers. In addition, and although disclosed as particularly applicable for use in the provision of accurate and substantially constant, materially reduced sample flow rates, it is believed clear that the method and apparatus of the invention are by no means limited thereto, but rather, are indeed applicable to significant advantage for use in fluid sample treatment and analysis systems having conventionally high, or even higher, sample flow rates.

While we have shown and described the preferred embodiment of our 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.

We claim:

1. In a method of pumping a stream of a series of fluid portions which are separated, each from the other, by a separating fluid portion, through a compressible pump tube by the concomitant, progressive occlusion of the latter longitudinally thereof at spaced locations thereon, the steps of, concomitantly progressively occluding said compressible pump tube only at spaced locations thereon corresponding to the locations therein of some, at least, of said separating fluid portions, whereby at least one of said fluid portions will be located in said compressible pump tube between said occluded locations thereon.

2. In a method as in claim 1 wherein, each of said fluid portions is of substantially equal extent in said compressible pump tube, each of said separating fluid portions is of substantially equal extent in said compressible pump tube, and said occluding of said compressible pump tube comprises the occluding thereof at substantially equally spaced locations thereon.

3. In a method as in claim 1 wherein, said occluding of said compressible pump tube comprises the occluding thereof at spaced locations thereon corresponding to the location therein of each of said separating fluid portions, whereby each of said fluid portions will be located in said compressible tube between said occluded locations thereon.

4. In a method as in claim 3 wherein, each of said fluid portions is of substantially equal extent in said compressible pump tube, each of said separating fluid portions is of substantially equal extent in said compressible pump tube, and said occluding of said compressible pump tube comprises the occluding thereof at substantially equally spaced locations thereon.

5. In a method as in claim 2 wherein, each of said separating fluid portions comprises a segment of air, a segment of liquid, and a segment of air, respectively, disposed in that order between said fluid portions, and said occluding of said compressible pump tube comprises the occluding thereof at locations thereon corresponding to the location therein of a said liquid segment.

6. In a method as in claim 3 wherein, each of said separating fluid portions comprises a segment of air, a segment of liquid, and a segment of air, respectively, disposed in that order between said fluid portions, and said occluding of said compressible pump tube comprises the occluding thereof at locations thereon corresponding to the location therein of a said liquid segment.

7. In a method as in claim 6 wherein, each of said fluid portions is of substantially equal extent in said compressible pump tube, each of said separating fluid portions is of substantially equal extent in said compressible pump tube, and said occluding of said compressible pump tube comprises the occluding thereof at substantially equally spaced locations thereon.

8. In apparatus for the pumping of a stream of a series of fluid portions which are separated, each from the other, by a separating fluid portion, through a compressible pump tube by the concomitant, progressive occlusion of the latter longitudinally thereof, means to occlude said compressible pump tube at a location thereon corresponding to the location therein of one of said separating fluid portions, and means to concomitantly occlude said compressible pump tube at another location thereon corresponding to the location therein of another of said separating fluid portions, whereby at least one of said fluid portions will be located in said compressible pump tube entirely between said occluded locations thereon.

9. In apparatus as in claim 8 wherein, each of said fluid portions is of substantially equal extent in said compressible pump tube, each of said separating fluid portions is of substantially equal extent in said compressible pump tube, and said means to occlude such pump tube are effective to occlude the same at substantially equally spaced locations thereon.

10. In apparatus as in claim 8 wherein, said means to occlude said compressible pump tube are effective to occlude the same at locations thereon corresponding to the location therein of each of said separating fluid portions, whereby each of said fluid portions will be located in said compressible pump tube between said occluded locations thereon.

11. In apparatus as in claim 10 wherein, each of said fluid portions is of substantially equal extent in said compressible pump tube, each of said separating fluid portions is of substantially equal extent in said compressible pump tube, and said means to occlude said pump tube are effective to occlude the same at substantially equally spaced locations thereon.

12. In apparatus as in claim 9 wherein, each of said separating fluid portions comprises a segment of air, a segment of liquid, and a segment of air, respectively disposed in that order between said fluid portions, and said occluded locations on said compressible pump tube correspond to the locations therein of said liquid segments.

13. In apparatus as in claim 10 wherein, each of said separating fluid portions comprises a segment of air, a segment of liquid, a segment of air, respectively disposed in that order between said fluid portions, and said occluded locations on said compressible pump tube correspond to the locations therein of said liquid segments.