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Schwind

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[54] **METHOD AND APPARATUS FOR OBTAINING MASS AVERAGE SAMPLES FROM A LIQUID STREAM**

[75] Inventor: **Richard G. Schwind,** Lahonda, Calif.

[73] Assignee: **Nielsen Engineering & Research, Inc.**

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[52] **U.S. Cl.** .....**73/422 R,** 73/423 R

[51] **Int. Cl.**.....**G01n 1/14**

[58] **Field of Search** ..73/421 R, 421 B, 422 R, 423 R

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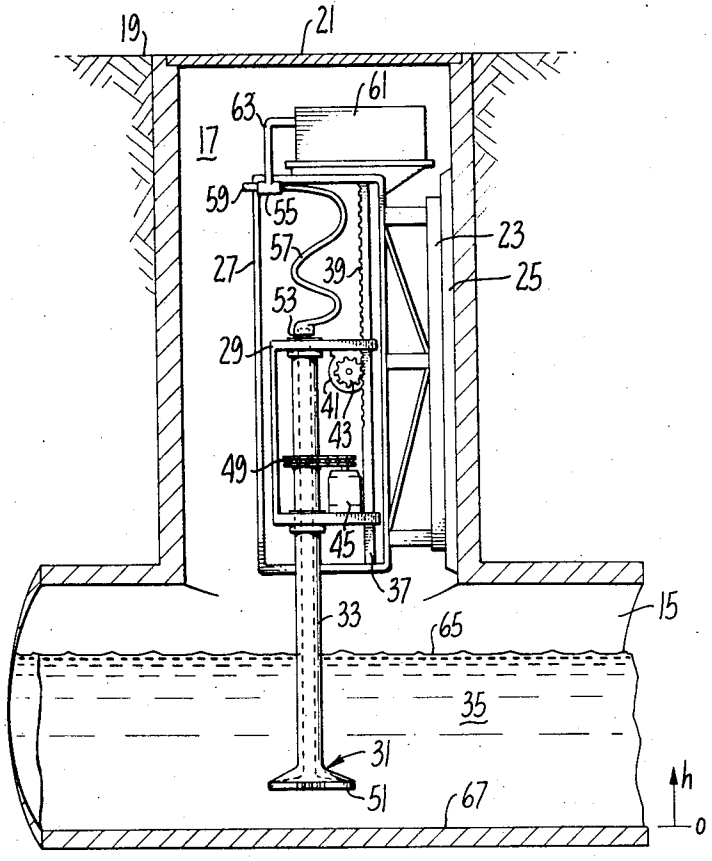
Primary Examiner—S. Clement Swisher
Attorney—Karl A. Limbach et al.

[57] **ABSTRACT**

An improved technique of extracting small samples from a liquid stream, such as a storm sewer, wherein each sample contains a representative portion from all levels of the stream. The relative sample proportions of liquid mass extracted from each elevation of the stream are directly related to the width of the stream at that elevation and the average velocity of the stream at that elevation. An apparatus is disclosed for carrying out this technique wherein a substantially continuous flow pump traverses across the liquid stream in a vertical direction with a rate of speed alongits path that is a function of a product of a reciprocal of the velocity and width functions along the height of the stream.

8 Claims, 7 Drawing Figures



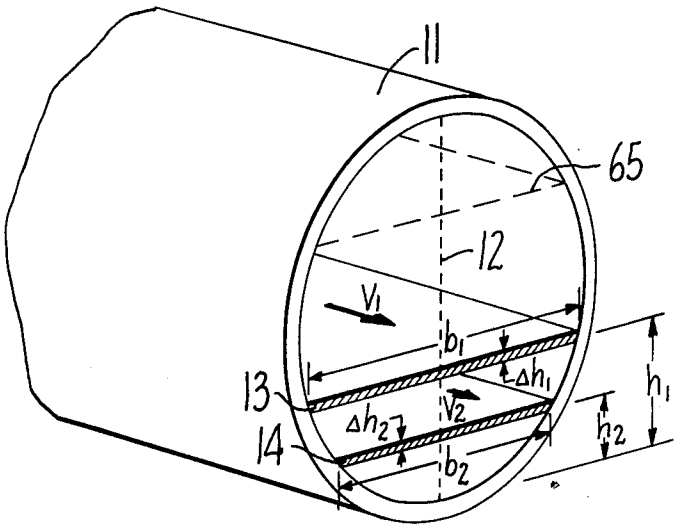


FIG. 1.

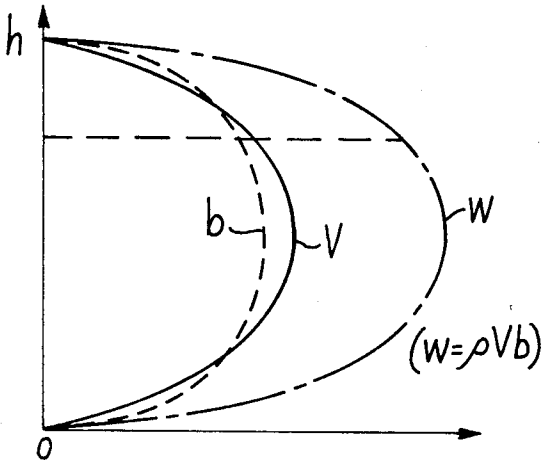


FIG. 2.

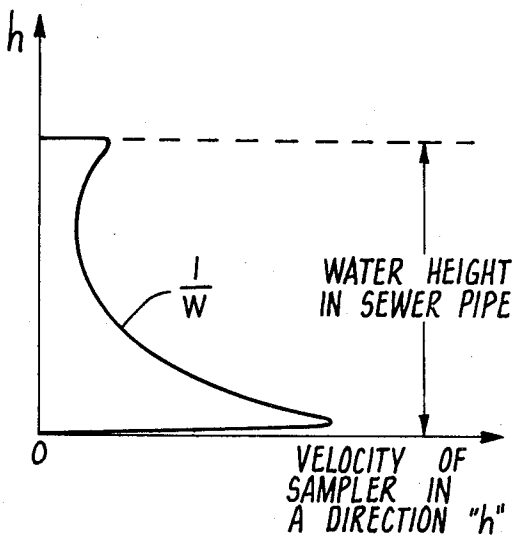


FIG. 3.

INVENTOR.
RICHARD G. SCHWIND
BY
Limbach, Limbach & Sutton
ATTORNEYS

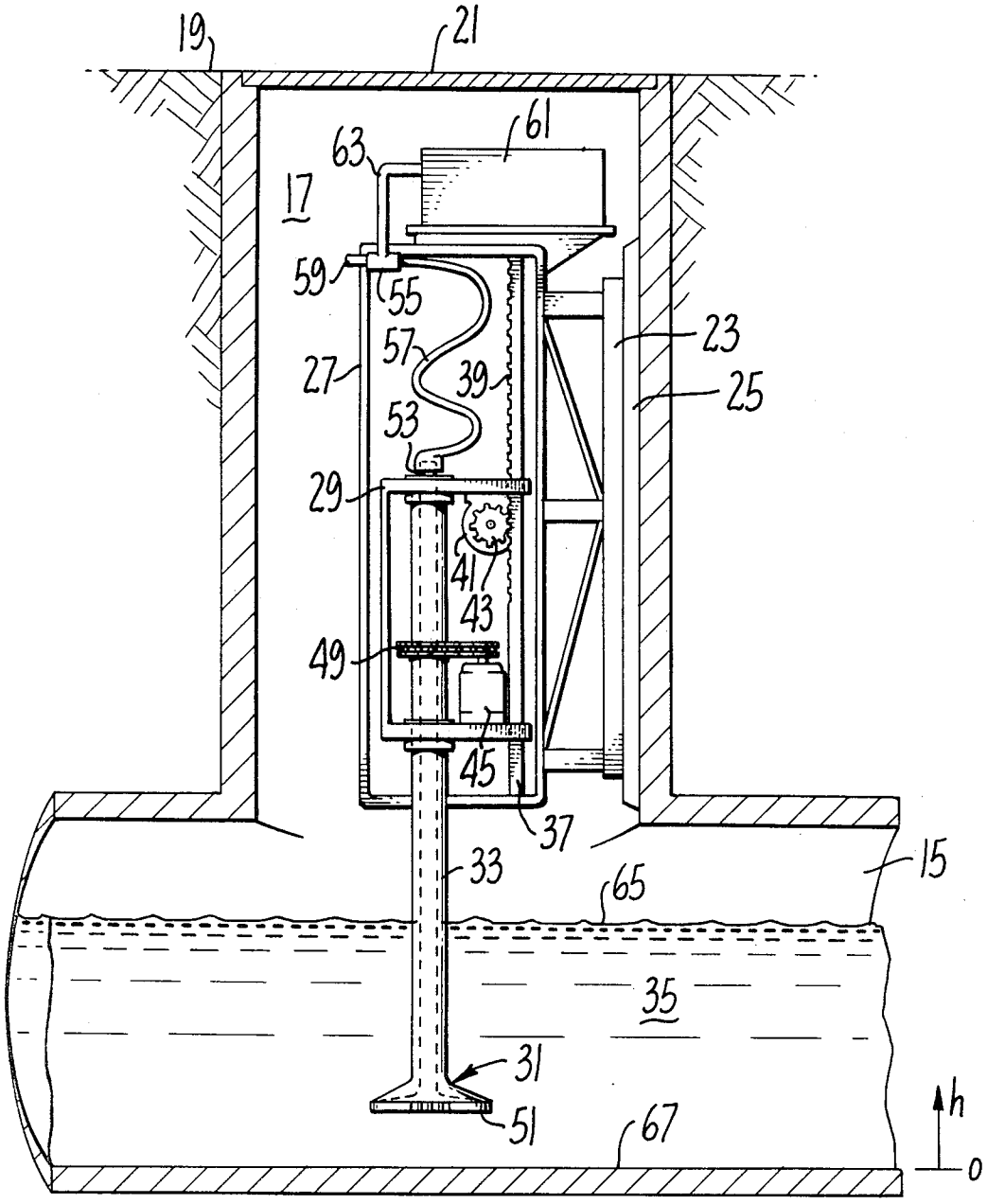


FIG. 4.

INVENTOR.
RICHARD G. SCHWIND
BY
Limbach, Limbach & Sutton
ATTORNEYS

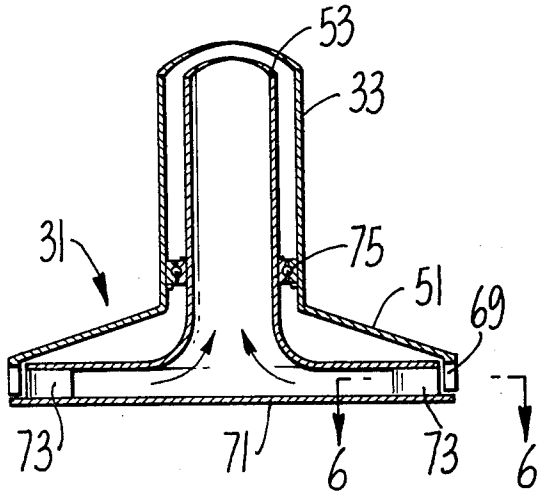


FIG. 5.

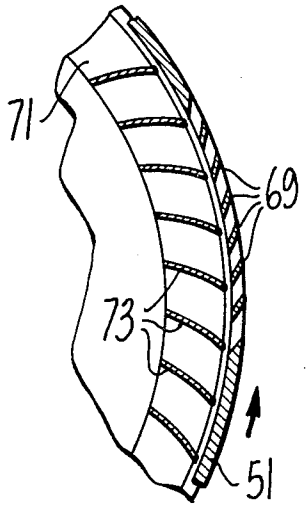


FIG. 6.

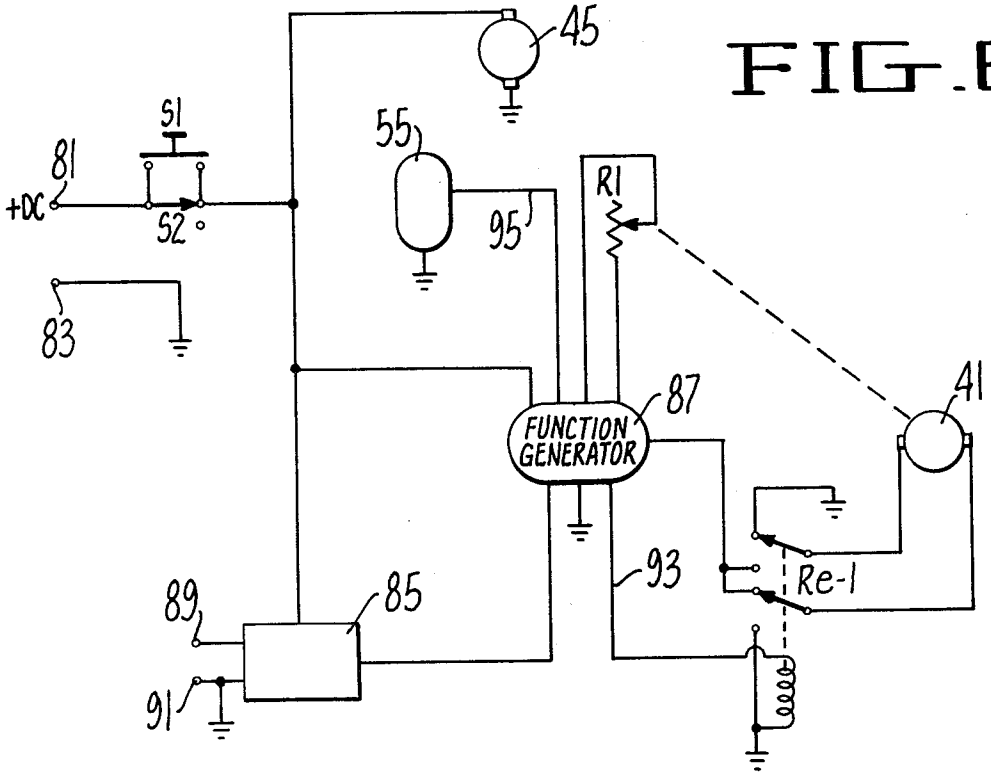


FIG. 7.

INVENTOR.
RICHARD G. SCHWIND
BY
Limbach, Limbach & Sutton
ATTORNEYS

METHOD AND APPARATUS FOR OBTAINING MASS AVERAGE SAMPLES FROM A LIQUID STREAM

BACKGROUND OF THE INVENTION

This invention relates generally to liquid stream sampling systems, particularly the sampling of a sanitary or a storm sewer in order to determine the pollutant content thereof.

Knowledge of the quality and quantity of flow in sewers is becoming increasingly important because of the desire to provide better treatment to the pollutant load that is carried in sewers. In order to provide the most efficient and economical treatment, it is necessary to know what the pollutants are and how the pollutant load varies with time.

In sanitary and combined sewers, it is becoming more common to require industrial and commercial firms to monitor their effluent dumped into the municipal sewer systems in order that the firms can be billed on the basis of their pollutant load injected into the sewers to help support the cost of sewer system operation. In order for firms to monitor and establish their pollutant loads for billing purposes, it is necessary to have representative samples of the flow in the sewer.

Further, in waste water treatment plants, it is highly desirable to obtain samples of the incoming sewer water over the depth of the flow to insure that any local concentrations of pollutants are sampled and that accurate loads of all pollutant levels are measured.

Floatable constituents of the sewer water, such as oil, grease, and wood materials, travel along the surface of the sewer water. Throughout the depth of the water will be suspended solids of dissolved materials such as chemicals, pesticides, nitrogen and phosphate nutrients, dirt, rags, and paper. Near and at the bottom of the sewer water will be the heavier material which may be in suspension or may be rolling or bumping along the bottom of the sewer. If the sewer water flow is very turbulent and well mixed, the concentration of each of the various pollutant constituents carried thereby will tend to be uniform as a function of the stream depth. However, the degree of mixing of the various pollutants probably changes in a given sewer with the flow velocity. The degree of mixing also varies between sewers and is dependent upon the sewer's physical characteristics which promote turbulence such as bends, enlargements, and spillways.

Existing sampling techniques and apparatus primarily extract a sample at only one point in a cross-section of a storm sewer water flow. This has the disadvantage that the sample does not contain a representative portion of all the pollutants in the water flow unless the flow happens to be homogeneous and well mixed. Therefore, it is a primary object of the present invention to obtain a sample from a liquid flow that contains pollutant constituents in the same proportion as carried by the total mass of sewer water.

It is further an object of the present invention to provide an improved sampling pump for immersion in the liquid flow which does not accumulate debris or easily become plugged.

SUMMARY OF THE INVENTION

According to the technique of the present invention, varying sample quantities are obtained at different

elevations within the liquid stream at a single location along the length of the stream. A sample is obtained by extracting a portion thereof at each level within the liquid stream according to a distribution that is directly proportional to a product of a horizontally average liquid velocity and the width of the stream as functions of elevation. This assures that the proportion of each constituent obtained in the sample is substantially the same as the proportion of that constituent in a given large mass of the liquid stream, even if the various constituents are not evenly distributed along the depth of the stream. A sample is preferably extracted continuously along a vertical line extending between the bottom and the top of the stream.

In any liquid stream, the velocity of its travel is significantly less near its bottom adjacent a solid containing boundary than at a midpoint of the stream. Therefore, the volume or mass of liquid that flows along the stream in an increment of height per unit time is significantly less near the bottom of the stream than at some midpoint elevation of the stream. Furthermore, variations in width of the stream at different elevations cause the mass flow per increment of height per unit time to vary at different elevations of the stream. The techniques of the present invention take into account the effects of these velocity and width variations as well as any density gradients, if significant enough to be accountable. A sample portion obtained from one incremental height of a liquid stream is substantially the same as the ratio that the mass flow per unit time of that incremental height of the stream bears to the total mass flow per unit time of the entire stream.

The sample collecting technique according to the present invention can be directed toward either the collection of separate samples or the accumulation of a single sample. Several samples may be taken in succession and each of these samples may either be stored in separate containers as a means of monitoring the changing constituent composition of the liquid flow, or the individual samples may be deposited in a single container for determining an average constituent composition of the liquid flow over a longer length of time. In using this latter technique, existing proportionality methods may also be employed wherein the individual samples are taken at intervals between which equal volumes or masses of liquid pass along the stream. When the velocity or height of the stream flow increases, the rate of taking samples increases.

One convenient way of implementing the sampling technique of the present invention is to draw a pump inlet at a uniform speed across a liquid stream from its bottom to its top in substantially a vertical path. The pump suction is not constant, however, but rather it is made to vary as a function of the position of the pump inlet along the height of the stream. The rate of sample volume flow varies along the height of the stream directly as a product of a vertical stream velocity profile and width functions vary. At elevations of the liquid stream having a low velocity of flow or a narrow width, the pump suction at its inlet is at a low level. An apparatus for carrying out this method according to the present invention is described in detail in a copending application of Jimmie Crumal, entitled "Apparatus for Extracting a Liquid Sample Over a Range of Depths of a Liquid Stream."

Another way of implementing the technique of the present invention is to maintain constant the rate at which a sample is extracted from a liquid stream and vary instead the speed at which a pump inlet is drawn vertically across the liquid stream. The speed of the pump inlet as a function of vertical position across the stream is inversely proportional to a velocity profile and width function of the stream along the vertical line. That is, at low flow velocity or narrow width portions of the stream, the pump opening is made to travel rapidly while at high velocity or wide portions of the stream the pump opening is made to slow down.

This second method of implementing the present invention is described hereinafter in detail and includes the use of an improved pump that is caused to traverse vertically across a liquid stream. The sampler pump is immersed in the liquid flow only during the time that a sample is being taken, thus reducing the chance of blocking the stream by accumulation of debris. Existing samplers which have a tube depending downward into the liquid stream on a permanent basis tend to promote blockage of the sewer. The sampler described hereinafter also traverses the entire depth of the liquid and has provisions for accommodating varying depths. This provides a more accurate sample than can be obtained by existing samplers that extract a sample at only a single elevation off the bottom of the stream regardless of the stream's level. Additionally, the sampler unit preferably can accept large particles near the bottom of a liquid flow without plugging. A sampling technique and apparatus having these features is particularly useful in the application of monitoring a storm sewer.

Additional objects and advantages of the present invention will become apparent from the following description when taken in conjunction with the drawings which describes a preferred embodiment of the present invention that is particularly suited for monitoring flows in sewers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a round storm sewer;

FIG. 2 shows velocity and width profiles of the storm sewer of a type shown in FIG. 1;

FIG. 3 graphically shows a desirable variation of velocity of the sampler across a liquid flow in the storm sewer of FIG. 1;

FIG. 4 is a side view of the principal components of a preferred sewer sampler apparatus;

FIG. 5 shows a cross-sectional view of the pump unit of FIG. 4;

FIG. 6 is an enlarged view of a portion of the pump of FIG. 5 taken across section 6—6; and

FIG. 7 shows in block diagram form the principal elements of a control system for the sampler of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 schematically shows a circular storm sewer pipe 11 having various quantities identified as an aid in analyzing sewer water flow through the sewer. A sample of sewer water is extracted along a substantially vertical line 12 that passes from the top to the bottom of the sewer pipe 11 and through its center. The surface of the fluid, indicated at 65, can be at any location, or the conduit can be full. It will be understood that the techniques of the present invention are not limited to extracting samples from a storm sewer pipe but are also of advantage in extracting samples from non-homogeneous liquid flows of other types, including flows in stream beds. However, the techniques of the present invention have particular advantage to sampling of sewer water flow.

Consider an incremental volume 13 of liquid flowing in the pipe 11 that has a height Δh_1 and a distance h_1 from the bottom of the storm sewer 11. The width of the incremental volume 13 is indicated by b_1 and its velocity along the length of the storm sewer is indicated by V_1. The mass of liquid which passes by a given point of the sewer pipe 11 in a given time in the incremental volume 13 is directly related to the width b_1 and the velocity V_1 of the incremental volume. A certain small percentage of this mass of sewer water is removed as part of a sample of the total flow in the sewer pipe 11.

The small percentage of a mass of sewer water is removed from every other incremental volume within the sewer water flow. Consider a second increment 14 of the total flow. Its width b_2 is less than that (b_1) of the first increment. Also, the flow velocity V_2 is less than the flow velocity V_1 of the first increment 13 since the second increment 14 is more restrained by friction with the bottom of the sewer pipe 11. The same small percentage as was taken from the mass of sewer water flowing in the first increment 13 is taken from the mass of sewer water flowing in the second increment 14 as a second sample. These two samples are then mixed together to form a composite sample with constituent proportions being substantially the same as the constituent proportions of the combined flows of the increments 13 and 14.

The same procedure can be followed for the remaining incremental volumes of Δh high across the stream of sewer water within the pipe 11. This is, of course, impractical but the beneficial results of such a technique can be realized by continuously extracting sample liquid by scanning a pump inlet through the stream along the substantially vertical path 12. The technique of the present invention compensates for a varying velocity of liquid flowing at different levels in the sewer pipe 11 as well as compensating for variations in the width of the sewer pipe.

Referring to FIG. 2, characteristic curves of the sewer pipe 11 and a liquid flow therein are shown. Regardless of the height of liquid within the sewer pipe 11, a velocity profile of the sewer pipe 11 takes on a characteristic form such as that indicated by the curve V of FIG. 2. The curve V shows the relative velocities of fluid flowing at different elevations within the sewer pipe 11 along the vertical sample line 12. The various points on this curve are average velocities across the horizontal dimension. Such a curve can be constructed for a given location along a sewer pipe by empirical observation coupled with theoretical calculation.

The width of the sewer pipe 11 as a function of its height h is shown by the dotted curve b. Of course, other shaped sewer pipes will have a different characteristic curve. For instance, a square sewer pipe would have a step function type of curve b wherein the width is uniform from the bottom to the top.

A product of the velocity profile curve V and the width curve b, when multiplied by the average density ρ of the sewer water, gives a characteristic mass flow distribution stream passing through the pipe **11** per unit time as a function of height h within the stream. In order to obtain a mass average sample according to the techniques of the present invention, the mass of the sample extracted as a function of the height h of the sewer pipe **11** substantially conforms to the total mass flow w. That is, the relative proportions of a sample that is withdrawn from the liquid flow within the sewer pipe **11** at various elevations therein along the vertical line **12** follow the shape of the mass flow curve w of FIG. **2**. At a height h where the magnitude of w is low, such as near the bottom of the pipe **11**, the portion of a sample extracted at that level is low. However, where the magnitude of the curve w of FIG. **2** is high, such as near the middle of the pipe **11**, the proportion of liquid sample withdrawn at that height h is high.

A preferred technique for extracting a sample according to these requirements is to immerse a liquid pump inlet within the liquid flowing in the pipe **11** and moving it along the vertical line **12** while the pump operates to remove a uniform volume of sample per unit time. In order to obtain the desired variation in the amount of sample obtained at various heights across the pipe, as discussed above, the pump inlet is traversed vertically along the line **12** at a varying rate of speed. The velocity function of the pump inlet is proportional to the inverse of the total mass flow curve w of FIG. **2**. This velocity function is shown in FIG. **3** wherein a given water height h_1 within the sewer pipe **11** is assumed to be less than the maximum height of the sewer. At positions along the vertical line **12**, wherein the rate of sewer water mass flow is low, the pump inlet travels at a high rate of speed so that a low amount of sample is extracted therefrom. Conversely at positions across the stream where the sewer water mass flow rate w is high, the pump input slows down in its travel across the stream to obtain a larger proportion of the sample from those positions across the stream. Of course, the rate of speed of the pump inlet travel must reach zero at the bottom of the pipe and at the top surface of the liquid flowing therein in order to reverse direction.

Referring to FIG. **4**, an apparatus is shown for performing the sample extraction by varying the rate of speed at which a pump inlet is traversed vertically across a sewer water stream. The sampler is shown in a typical installation wherein a sewer pipe **15** includes a manhole **17** communicating with the sewer and a ground level **19**. A manhole cover **21** provides access to the sewer and to the sampler that is installed within the manhole **17**. A mounting pad **23** of the sampler unit is rigidly mounted on the side of the manhole through a sewer mounting pad **25**. A box-like frame **27** of the sampler unit is rigidly attached to the sampler mounting pad **23**.

A translating frame **29** slides up and down within the sampler frame **27** as a means of translating a pump **31** at the end of elongated tubular member **33** up and down within the sewer water **35**. The translating frame **29** slides up and down on a guide bar **37** that is rigidly attached to a side of the sampler frame **27**. A rack **39** is also positioned vertically and fixed to the sampler frame **27**. An electric motor **41** is attached to the translating frame **29** for rotatably driving a pinion gear **43** that mates with the rack **39** to give motion to the translating frame **29** and thus to the pump head **31** within the sewer waters.

Power is applied to the pump by means of a second electric motor **45** that drives the elongated tubular member **33** by means of a chain or some other rotatable connection **49**. At the end of the tube **33** is the pump unit **31** which includes a partial admission rotor **51** that is attached to the rotating elongated tube **33**. Rotation of the partial admission rotor **51** forces fluid from the sewer **35** through the stator **71** into a second elongated tube **53** that is positioned concentrically within the rotating tube **33**. The elongated tube **53** is fixed to the translating frame **29** while the outer rotating tube **33** is connected to the translating frame **29** through appropriate bearings that allow rotation but no longitudinal motion with respect to the translating frame **29**. Liquid pumped up through the non-rotational tube **53** is guided to a three-way solenoid valve **55** by a flexible tube **57**. The solenoid valve **55** is of a type that can direct liquid flowing in the flexible tube **57** either to an outlet **59**, for discharge back into the sewer **15**, or into an accessory package **61** by means of a liquid tube **63**. The accessory package **61** contains the power supply and control elements for the sampler, and also contains a rack having a plurality of sample containers and a mechanism for indexing the rack in a manner that sample sewer water passing through the tube **63** will go into a different container each time a new sample is taken.

Between the samples, the sampler of FIG. **4** is at rest with the pump unit **31** drawn up above the surface of the sewer water **35** and immediately adjacent the underside of the fixed sampler frame **27**. Since nothing depends downward into the liquid sewer flow **35** except when a sample is being taken, the sampler provides very little undesirable obstruction to the flow of the sewer waters. When a sample is to be taken, the pump drive motor **45** is energized which rotates, with respect to the translating frame **29** of the pump, the outer elongated tube **33** and thus the partial admission rotor **51** of the pump. The solenoid **55** is initially in a position which causes liquid to be discharged back through the pipe **59** into the sewer **15**.

The translating drive motor **41** is then energized which causes the pump to travel downward until it strikes a surface **65** of the sewer water **35**. The height of the surface **65** is sensed at this point and recorded in the control circuits within the accessory package **61**. The pump **31** continues its descending course down through the sewer water **35** until it reaches its bottom **67** at which time the drive motor **41** reverses and pulls the pump **31** upward. The pump **31** will only rise to the surface **65** of the sewer water **35** until it is again reversed in direction to head downward. The pump **31** so reciprocates through the sewer water flow for several cycles until a well mixed sample flow is established through the tube **53** from the pump **31**. When this occurs, the control circuit within the accessory package **61** causes the solenoid valve **55** to switch to a position so that the flow in the tube **57** from the pump flows through the tube **63** and into a bottle for collecting a sample. This flow continues for one complete translational cycle of the pump head **31**; that

is, a sample is collected while the pump head **31** travels downward from the surface **65** of the sewer water **35** to the bottom **67** and back again to the surface **65**. After this cycle has occurred, the pump head **31** is again withdrawn from the sewer water **35** and the solenoid **55** is returned to its position for discharge of the sample drawn by the pump **31** through the hose **59** back into the sewer water **35**. The fluid in the tube **53** and the tube **57** will then drain out through the pump head **31**. The sample bottle rack within the accessory package **61** is then indexed and an empty bottle is placed in a position to receive a new sample through the tube **63** when the next sample is taken.

The pump **31** in its preferred construction is shown in more detail in FIGS. **5** and **6**. The rotating tube **33**, driven by the motor **45** of FIG. **4**, imparts rotary motion to the partial admission rotor **51** which is generally solid except for one or more openings with rotor blades **69** firmly attached thereto. The rotor **51** is driven in a direction to cause the rotor blades **69** to force liquid radially inward. A stator **71** includes a plurality of stator blades **73**. The rotor **51** imparts velocity energy to liquid and this energy is partially converted into a static pressure increase by the stator blades **73** as the liquid flows radially inward and up through the interior of the stationary tube **53**. The rotating tube **33** and the stationary tube **53** are held concentrically with respect to one another and held spaced apart by appropriate means such as a bearing **75** shown in FIG. **5**.

The diameters of the stator **71** and of the rotor **51** of the pump **31** shown in FIGS. **5** and **6** are made to be large enough to keep the rotational speed low to keep vibration to a minimum. The height of the rotor blades **69** and associated stator blades **73** are made large enough to handle prevalent particles of sewer water in order to prevent plugging of the pump. However, with such a large diameter rotor and stator and with the high rotor and stator blades, an excessive amount of sample liquid may be withdrawn if the rotor **51** includes the blades **69** completely around its perimeter. Therefore, the portion of the perimeter of the rotor **51** with an opening for fluid to flow therethrough is limited as a means of limiting the amount of sample that is withdrawn. Placing the rotor blades on the outside of the pump stator has an advantage of being able to knock away very large objects in the sewer water, such as boards or large rocks, and thus prevent such objects from interfering with the pump operation.

The translating frame **29** and the pump assembly **31** as shown in FIG. **4** are not translated up and down at a constant rate of speed but rather are translated with a velocity that is a function of the height within the sewer **15**. The velocity function is inversely proportional to a product of the velocity profile (V of FIG. **2**) of the sewer **15** and its width (*b* of FIG. **2**) as a function of the height (*h* of FIG. **2**) of the sewer. The velocity of travel of the sampler pump is made to conform as closely as possible with the inverse of the mass flow function *w*, as discussed hereinabove with respect to FIG. **3**. This varying velocity is accomplished by varying the speed of the electric motor **41** of the FIG. **4**. The motor **41** is preferably of a direct current type so that the voltage applied to its field windings directly controls the speed of the pinion gear **43**, and thus the speed of travel of the pump **31** vertically through the sewer water **35**. There are a number of known function generators that can be inserted electrically in series with the power supply to the motor **41** for controlling the velocity of the pump **31** as a function of its position along the height of the sewer **15**.

FIG. **7** schematically illustrates a control system for operating a sampler apparatus of FIGS. **4–6** in the manner described above. A direct current voltage source (not shown) is connected at terminals **81** and **83**. A push-button switch **S1** is connected with the terminal **81** and is of a type to make a momentary contact so long as pressure is applied thereto. Another switch **S2** is parallel with the switch **S1**. When the switch **S1** is depressed, the sampler apparatus is energized and begins its sequence. The switch **S1** locks the switch **S2** in a conductive state. At the end of the sequence the switch **S2** is moved to disconnect the sampler from its power source.

When the sampler is energized, the motor **45** causes the pump rotor to be given motion. The translating motor **41** is also energized which causes the pump head **31** to descend. An appropriate surface sensor **85** is provided which generates a signal when the pump head strikes a surface **65** of the sewer water stream **35**. A function generator **87** takes this signal and evaluates the depth of the liquid stream. The height of the pump head **51** when it first strikes the liquid surface **65** is also sent to the function generator **87** by a potentiometer **R1**. The potentiometer **R1** is mechanically driven by the translating motor **41** and thus emits a signal which is proportional to the height of the pump head **57** within the sewer **15**. The surface sensor **85** may utilize a pair of terminals **89** and **91** which are attached to the bottom of the pump head **31** so that an electrically conductive path is formed between them when the pump head **31** first reaches the liquid stream surface **65**.

The function generator **87** sends a varying voltage to the translating motor **41** through contacts of a relay **Re-1**. The voltage varies as a function of the height of the pump head **31** in a manner discussed above with respect to FIG. **3**. Since the height of the surface **65** of the liquid stream **35** has been noted by the function generator **87**, a signal may be transmitted through a line **93** therefrom to the relay coil each time the potentiometer **R1** sends a signal to the function generator **87** that indicates the pump head **31** is at the liquid stream surface elevation. This signal will cause the relay **Re-1** to change its state which results in reversing the polarity on the d.c. translating motor **41**. By this method the pump head **31** is caused to translate back and forth across the stream **35** a specific number of times after which the function generator **87** sends a signal to the solenoid valve **55** through a line **95**. The solenoid **55** is switched to divert sample fluid into a container. After one complete translational cycle of the pump head **31**, the pump head **31** is removed from the stream and returned to its rest position at which time the switch **S2** is opened to remove all power from the sampler until the switch **S1** is again momentarily depressed. The switch **S1** may be replaced with a timer for unmanned sampler operation.

The present invention has been described with respect to a specific sampling method and apparatus, but it will be understood that the scope of the invention is limited only by the scope of the appended claims.

What is claimed is:

1. A method of extracting a liquid sample across a vertical line of a liquid stream flowing through a container such as a pipe, comprising the steps of:

determining a stream flow relative velocity function along a substantially vertical line across said container,

determining a container width function along said substantially vertical line across said container, and

removing a sample quantity of liquid along said substantially vertical line, portions of said sample being collected all along said line according to a relative distribution that is a function of a product of the relative velocity and width functions of said container across said line.

2. The method as defined by claim 1 wherein the step of removing a sample includes drawing a liquid pump inlet along said substantially vertical line with a velocity that varies along said line inversely as a function of a product of said relative velocity and width functions, the pumping rate of said pump being maintained substantially constant.

3. The method as defined by claim 1 wherein the step of removing a sample includes drawing a liquid pump inlet at a uniform speed along said substantially vertical line, the pumping rate caused to vary along said line directly as a function of a product of said relative velocity and width functions.

4. A method of extracting a liquid sample from a stream flowing in a fixed conduit having given flow velocity and width variations as a function of vertical position across said conduit, comprising the steps of:

translating a pump inlet with continuous motion vertically across said conduit, said pump operating to remove a substantially constant mass of liquid as a function of time,

controlling the speed of said pump inlet translation as a function of position across said conduit according to a function that varies inversely with a product of said given conduit flow velocity and width functions, and

collecting into a container the liquid sample discharged by said pump.

5. The method as defined by claim 4 wherein the sample is collected into the container during at least one full traverse of said pump inlet from the stream surface to the bottom of the conduit.

6. The method as defined by claim 5 wherein said fixed conduit is a sewer and said stream is a sewer flow.

7. Apparatus for sampling a sewer water in a sewer of fixed dimensions, comprising:

a liquid pump,

a sample flow inlet opening to said pump,

a discharge opening communicating with said pump,

means for vertically translating said pump inlet opening continuously across at least a portion of said sewer, and

means for varying the speed of the pump inlet translation across the sewer as a function of the pump inlet's vertical position in the sewer according to a function that is inversely proportional to the total mass flow of sewer water as a function of its height.

8. A sampling apparatus according to claim 7 wherein said pump comprises:

a rotationally fixed circularly shaped stator having a plurality of generally radially extending stator blades fixedly attached thereto and adjacent an outer circumferential edge of the stator,

a circularly shaped rotor surrounding said stator and having a plurality of blades positioned in an opening along a circumferential surface of the rotor to force liquid radially inward through said stator blades, said rotor opening being said pump inlet,

means for conducting liquid from within the stator blades to said discharge opening, and

means for giving rotary motion to said rotor with a uniform angular velocity.

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