PATENT SPECIFICATION (11) 1 566 154

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(21) Application No. 11318/77 (22) Filed 17 March 1977 (19)
(31) Convention Application Nos. 2 613 212(32) Filed 27 March 1976
2 658 799 24 Dec. 1976 in
(33) Fed. Rep. of Germany (DE)
(44) Complete Specification published 30 April 1980
(51) INT. CL.³ G01N 11/08 33/48
(52) Index at acceptance
G1S 1M 1T

(54) A METHOD OF MEASURING THE FLUIDITY OF LIQUIDS FOR MEDICAL AND PHARMACEUTICAL PURPOSES, AND APPARATUS FOR PERFORMING THE METHOD

(71) We, GERHARD WEBER, of Wackenroderstr. 31, 8500 Nuremberg and SIEGFRIED PETER, of Lange Zeile 138, 8520 Erlangen, both citizens of the Federal Republic of Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention primarily concerns a method of measuring the fluidity of liquids, in capillary tubes, for medical and pharmaceutical purposes. The contemplated liquids include for instance blood, infusion and transfusion solutions, and other liquids. The invention also relates to apparatus for performing the method.

Examination of the fluidity of blood and other physiological liquids, such as serum or lymph occupies a position of increasing importance and interest in modern medical practice. The principal desideratum is a rapid and precise measurement of the viscosity of the liquid. For instance, a change in the viscosity of the blood of a patient within a given period of time or in response to a treatment may be a significant factor in the diagnosis and therapy of a disease. For instance, in a suspected case of thrombosis precise measurements of the coagulability of the blood would be desirable and an important indication would be that provided by the viscosity of the blood. During a particular course of treatment it is also often desirable to keep the viscosity of the blood of a patient under continuous observation, i.e. to carry out a large number of consecutive measurements at short intervals of time.

Similar or like problems arise in the pharmaceutical industry, for instance during the production of a serum, a transfusion liquid, and so forth in relatively small quantities, and it is nevertheless desired during the process of production to be aware of the viscosity of the liquid continuously.

In all the above mentioned cases the use of the methods conventionally employed of measuring viscosity in industrial processes, which comprise allowing a defined volume of liquid to cow through a capillary tube, measuring the viscosity by reference to time, and then discarding the tested volume of liquid, cannot be employed. This loss of liquid may not matter much when large volumes are being produced, but it cannot be accepted if the quantities that are available for such a measurement are only small and limited, such as blood taken from a patient or in the case of a serum when only a relatively small quantity is being prepared.

The measurements of viscosity which were hitherto carried out in such circumstances, for instance with the aid of rotary viscometers, such as the Couette, cone-plate viscometers, or the Hess viscometer, have diverse defects which are liable to introduce error. For example, when measuring the viscosity of blood a circumstance which is principally responsible for misleading results is that the time elapsing between the taking of a sample and the actual carrying out of the measurement is too long. When exposed to atmospheric oxygen or to the walls of its containing vessel the viscosity of a sample of blood already begins to change. Coagulation of the blood or rather its initial stages set in and vitiate the result. It is therefore the practice to stop or inhibit coagulation by the addition of heparin etc. before a viscometric measurement is actually performed. However, the fluidity of the blood is thereby considerably altered and in a manner that is not subject to control.

It is therefore an object of the present invention to provide a method, as well as an apparatus for performing the method, which for medical and pharmaceutical purposes will enable the fluidity of a liquid to be quickly and easily determined without any part of the liquid being lost and being discarded. Another object of the invention is to prevent the sample liquid from coming into contact with the ambient air or with parts of a component, such as a pump likely to affect the properties of the liquid.

Yet another object is to provide apparatus that can be easily and quickly cleaned without having to be dismantled or taken apart.

According to the invention, there is provided a method of determining the fluidity of a liquid, such as of blood or serum, comprising the steps of drawing the liquid from a vessel through a measuring cell comprising a capillary tube into a reservoir unit, thereafter returning the liquid to said vessel through the measuring cell at a flow velocity that remains constant for a given period of time, and measuring the pressure difference which becomes established between the two ends of the capillary tube, the measured liquid being drawn into and expelled from the measuring cell by pump means acting through an interposed buffer liquid, such as an infusion solution, the liquid to be measured being drawn no further than will ensure that the pump means are wetted only by the buffer liquid, and the entire volume of the measuring cell and reservoir unit not filled with the liquid to be measured being filled with the buffer liquid.

This method has several advantages which are of special importance in the context of its application in medicine and pharmaceutics. The entire liquid that is to be measured is returned into the containing vessel from which it has been withdrawn, so that there is no loss. Once a connection to the containing vessel has been made many measurements can be carried out in rapid succession for long periods of time. This is particularly important when the changing fluidity of a liquid is to be kept under observation; as for instance, the viscosity of the blood of a human patient to assess the effects of a particular treatment, such as infusions, transfusions, the administration of particular drugs or during an operation and so forth. In pharmaceutical production, for instance, the viscosity of a liquid that is being prepared can be continuously monitored so that in the event of any deviation from a desired viscosity level steps can be taken to vary a parameter in the manufacturing process and the deviation corrected. If desired this may be done automatically by the provision of a controller which is fed with the results of the measurements. In other words, the overall result is a method of continuous measurement and possibly also of continuous control adapted to work without significant loss of liquid that is to be measured and/or controlled.

Moreover, the above described risk of the properties of such a liquid changing during an unavoidable period of delay before the measurement can be made and/or as a result of contact between the liquid and air is entirely eliminated. This is a matter of primary importance in viscosity measurements performed on human blood. On the one hand, the present method by its rapidity eliminates the risk to the patient involved in coagulation of the blood and, on the other hand, the true fluidity of the blood can be ascertained, faulty results caused by incipient coagulation and/or by the introduction of anticoagulants being avoided. The measurement is performed on the living unaltered blood which can be returned to the blood stream whence it was taken. These measurements which can be analogously performed on blood substitutes, plasma expanders, etc., are of great importance in medicine for the purpose of diagnosis, therapy and research. This importance is enhanced by the advantage that has already been mentioned, namely that the measurements can be very quickly and hence consecutively performed so that a continuous fluidity curve can be plotted in a very short time.

As the measured liquid is drawn into and re-expelled from the measuring cell by pump means acting through an interposed buffer liquid, such as an infusion solution, the liquid which is to be measured, e.g. blood, cannot come into contact with moving mechanical parts of the apparatus which might conceivably chemically react with the liquid or give rise to the formation of air bubbles. If during the return of the blood a minor volume of this buffer solution, which must be a compatible solution, such as an infusion solution, should happen accidentally to enter the patient's blood stream, then no harm will be done. An infusion solution has no adverse effects on the blood. Another advantage of this particular step is that the buffer liquid, e.g. the infusion solution, can be used when the measurements have been completed to flush out and clean the measuring capillary tube and the tube in the reservoir unit, as well as the connecting pipe lines.

The invention also relates to apparatus for performing the proposed method, comprising a measuring cell comprising a capillary tube, means connecting the cell to a vessel containing the liquid to be measured and to a reservoir unit, and means for measuring the pressure difference across the capillary tube of the liquid that passes therethrough, the reservoir unit being connected by a pipe line to pump means for drawing in and returning the liquid to said vessel, the pump means acting through an interposed buffer liquid, such as an infusion solution, and being arranged such that the liquid to be measured is drawn no further than will ensure that the pump means are wetted only by the buffer liquid, the entire volume of the apparatus not filled with the liquid to be measured being filled with the buffer liquid.

Such apparatus will permit the proposed method to be performed. The apparatus is

easy to handle and the measurements can be quickly made. The construction of the apparatus is relatively straightforward and thus not liable to develop faults and the cost of production is correspondingly low. When the liquid is forced back through the capillary tube the presence of the reservoir unit functions to generate preliminary shear and therefore reduces the length of the capillary tube over which non-uniform flow occurs due to entry effects. The results of the measurements may either be visually read or recorded, or converted into electrical signals and introduced into a computer which may be provided with facilities for print-out of the results.

Other aspects and advantageous features of the method according to the invention and of the apparatus will now be described in greater detail, purely by way of example and reference made to embodiments of the apparatus which are shown in the accompanying drawings in which

Figure 1 is a diagrammatic representation of apparatus according to the invention,

Figure 2 is a longitudinal section of one form of construction of the measuring cell containing the measuring capillary tube,

Figure 3 is a section taken on the line A—B in Figure 2 and

Figure 4 is a section taken on the line C—D, omitting the part marked 1^1 in Figure 2,

Figure 5 is an example of a measuring cell with capillary tube in longitudinal section,

Figure 6 is a section according to line VI—VI in Figure 5.

Referring to the drawings, the liquid upon which a measurement is to be performed, e.g. the blood of a patient is drawn through a pipe 1 into a measuring cell 2 containing a capillary tube 3. The measuring cell 2 is connected by a further length of pipe 4 to a reservoir unit 5 containing a reservoir tube 6 which is a capillary tube. The other end of the reservoir unit is connected by yet another length of pipe 7 containing a stop valve 8 to a piston pump 9. Between the stop valve 8 and the piston pump 9 this pipe 7 communicates with a branch pipe 10 for the admission of an auxiliary buffer liquid adjusted so that it is compatible with the liquid that is to be measured. This branch 10 can be closed by another valve 11. If the measured liquid is blood, it is advisable that all parts, pipe-lines or connections of the apparatus with which the blood makes contact should be made of polyamide, platinum, or a high quality chromium-nickel stainless steel. Experiments have shown that compared with other materials the proposed materials substantially retard the coagulation of the blood that flows through such parts. More particularly, the connections 1 and 4 of the measuring capillary tube 3 to the vessel supplying the blood and to the reservoir unit 5 as well as the pipe connection 7 from the reservoir unit to the means for drawing the blood through the apparatus by suction and then forcing it back again, may consist of lengths of flexible polyamide tubing, whereas the measuring capillary tube 3 and the tube 6 in the reservoir unit 5 may preferably consist of platinum or stainless steel. This is preferred because the diameter of the capillary should be very precise. Such close manufacturing tolerances are easy to observe if this component is made of platinum or stainless steel. The employment of platinum or stainless steel for the tube 6 in the reservoir unit is advisable for manufacturing reasons. On the other hand, the less costly polyamide is quite satisfactory for the connections or pipes 1, 4 and 7. A polyamide pipe can be relatively long and its flexibility makes it more suitable for attaching it to the human body and for making the required connections than a rigid pipe.

Before the measurement begins the entire apparatus is filled with the buffer liquid, such as an infusion solution. The pipe 1 which does not affect the blood and which, more particularly, does not cause it to coagulate, is connected to the containing vessel, for instance by means of a catheter to the vein or right hand ventricle of the heart of a patient, and the blood or liquid is drawn into the apparatus, for instance in the apparatus in Figure 1 by the displacement of the plunger in pump 9 downwards. The blood therefore flows through the measuring capillary tube 3, the pipe 4 and the tube 6, the infusion solution being displaced. The reservoir unit 5, i.e. the tube 6 which it contains, is filled with the measured liquid, e.g. the blood, only as far as will ensure that no blood enters the pipe connection 7 from the reservoir unit 5 to the pump 9. This will definitely prevent the liquid that is to be measured from coming into contact with the pumping system or with the valves 8 and 11.

In the apparatus illustrated in Figure 1 the pump plunger 9 is then pushed upwards again, causing the buffer liquid to transmit a corresponding thrust to the liquid that is to be measured, which therefore now flows back through the measuring capillary tube 3, being displaced from the reservoir unit.

If the pump 9 should not generate a constant pressure the interposition of the reservoir unit ensures that the velocity of flow of the liquid that is to be measured through the measuring capillary tube 3 will in fact be substantially constant, at least for a certain period of time sufficient for the measurement to be completed. The measuring elements in this apparatus may be precision pressure gauges 12 at each end of the capillary tube 3. A reading instrument 13 may be provided to indicate the difference between

the two pressures or in a preferred embodiment of the invention, the measured quantities may first be converted into electrical quantities. These electrical quantities in the form of currents or voltages derived from the pressure gauges, and possibly the current controlling the pump are fed to a computer, not shown in the drawing, which is arranged to print out the measured results, in the desired units or dimensions, for instance in a viscosity measurement in poises, as well as to convert the results of the measurements into a continuous fluidity curve. It may here be observed that the method according to the invention is particularly suitable for the performance of measurements on low viscosity liquids.

Operations of the pump 9, e.g. the reciprocation of the plunger, may be automatic and proceed by reference to prescribed data, for instance by control of a motor operating the pump. It is thus possible to carry out measurement series in which the return flow of the liquid proceeds at specific though consecutively changing velocities. The velocity of flow of the measured liquid through the measuring capillary tube 3 is a function of the cross section of flow and the volume of liquid displaced per unit of time by the pump 9. Hence, after the apparatus has been filled the sample volume present in the measuring cell 2 and in the reservoir unit 5 can be forced through the capillary 3 by pushing the plunger of the pump 9 upwards at velocities which can be kept constant for a period of about 2 to 4 seconds. The pressure differential between the ends of the capillary tube which results when the pump displaces a given volume per unit of time is measured by the above described precision pressure gauges 12. A series of measurements for the determination of ten points of a fluidity curve will therefore take only about one minute to complete. If for rheological reasons (establishment of equilibrium of flow) a flow of longer duration at a given velocity of low is desirable, then the entire sample volume of liquid contained in the reservoir unit can be forced through the capillary tube 3 at unchanging velocity. The above mentioned computer can then provide a number of data, such as velocity of flow, shear stress, as well as viscosity. Moreover, these data can be fed to the data storage of a therapeutic or pharmaceutical programming unit which may control infusions and treatments during the treatment of a patient, and in pharmaceutical production, steps such as additions to the measured liquid and changes in processing parameters, such as temperature and so forth.

The mixing zone in which the liquid that is to be measured, for instance blood, mixes with the buffer liquid, such as an infusion solution, should be relatively short, e.g. 10 cms in length compared with a length of about 2 to 4 metres of the reservoir tube 6. In the illustrated example the diameter of the tube 6 will be about 2mm, whereas the diameter of the measuring capillary tube 3 is about 1 mm, its length in this example being about 30 cms. However, it will be readily understood that the invention is not intended to be limited to these particular diameters and lengths which are here given purely by way of example. The diameter of the capillary should be a multiple, for instance ten times the diameter of the largest object contained in the liquid, such as the body of a cell. Moreover, the capillary should also be long enough to reduce the entry and exit effects on the viscosity measurement to negligible proportions. Furthermore, the above data may be varied according to the nature of the measured liquid. In accordance with the above explantions the so-called mixing zone will be located near the end of the reservoir tube where this joins the connecting pipe 7. It should be enough to surround the measuring cell 2 and the reservoir unit 5 with a conditioning or tempering jacket 14 through which a thermostaticaly controlled fluid can be circulated by pipe means 15. On the other hand, the pipes 7 and the pump 9 need not be temperature controlled. When the measurement or series of measurements has been completed, valve 8 is closed and valve 11 opened to permit an appropriate volume of buffer liquid to be drawn in through the branch pipe 10 by the pump 9. Valve 11 can then be reclosed and valve 8 reopened and the measuring system flushed out with the buffer liquid, such as an infusion solution. The entire apparatus should be continuously filled with buffer liquid except for the volume occupied by the measured liquid whilst this is being drawn in and forced out through the measuring unit 3 into and from the reservoir unit 5, as has been described.

As above stated, the method according to the invention can also be used in pharmaceutical practice, for instance during the production of pharcaceutical preparation. For example, it may be important to know the viscosity of solutions of polymers. The preparation of sera has already been mentioned which, like blood, must also be prevented from coming into contact with air. Frequently pharmaceutical products are prepared in small quantities and in such cases it will certainly be desirable that none of the measured liquid is lost. For example, it has been found that when performing the proposed method in apparatus according to the invention the plotting of a continuous fluidity curve obtained from measurements at 10 different velocities of flow required only 12 mils of liquid and this would still be of use for carrying out other medical tests.

A possible form of construction of the measuring cell 2 is illustratively shown in Figures 2 to 4. 1^1 is the taper socket for the reception of the end of the entry pipe 1. The pressure gauge 12 contains a diaphragm 16 which is exposed to the pressure head of the liquid as it passes through a passage 17. In this arrangement the diaphragm is provided with strain gauges which generate electrical signals that correspond to the existing pressure, and transmit them to the computer. Naturally pressure gauges of some alternative type and construction could also be fitted, provided they were capable of performing functions required for the purposes of the invention. The pressure gauge 12 is here shown fitted into a pipe union 18 incorporated in the pipe line for conveying the liquid.

Part 19 serves for securing the pressure gauge 12 in the pipe union 18. The pressure gauges 12 are so disposed at each end of the measuring capillary tube that the creation of sharp edges and angles of less than 90° is avoided to ensure that flow is not significantly affected or impaired in these zones. The cross section of the pipe union 18 which is fitted with the pressure gauge and particularly the cross section of the passage 17 is square (c.f. Figures 3 and 4) to permit the pressure gauge 12 to be a flush fit in the pipe union and the diaphragm 16 to be a flush fit with the inside surface of the passage 17. Moreover the entry and exit openings 24 of the pipe union are conically flared, diverging like Laval nozzles and merging into the convergent tapers 25. This shape is flow dynamically favourable besides permitting these parts to be reliably and quickly cleaned. The diameter of the passage 17 is several times greater than the cross section of the capillary tube 3 so that no pressure loss that would adversely affect the measurement can occur outside the capillary.

The measuring cell 2 proper containing the measuring capillary tube 3 is surrounded by a jacket 20 and a liquid for the maintenance of a constant temperature can be circulated through the interior 21 of the jacket. 22 are holders for the measuring capillary tube 3 and the parts are held together by a milled ring nut 23. The right hand end of the capillary tube in Figure 2 communicates with a similar pipe union 18 to that on the left containing a pressure gauge 12, diaphragm 16, and retaining screw ring 19.

Figures 5 and 6 show a further working example of the arrangement of the pressure gauge. As in the previous example of Figures 2 to 4 pressure gauges are provided on both ends of the measuring capillary, whereupon an indicatian of the pressure difference is obtained. These pressure gauges are arranged so that the pressure change in the liquid to be measured does not result in any significant deformation of the diaphragm. Such pressure measuring devices can for example be diaphragms which are provided with strain gauges.

As against the arrangement of Figures 2 to 4, with the arrangement according to Figures 5 and 6 the pressure measuring devices are on the edge of the flow cross-section of the liquid inlet or outlet pipe to the capillary 3 and are acted upon by the pressure of the liquid. In the drawing only one of the two ends of the capillary is shown. The following described parts of the pressure cell are likewise to be seen as a mirror-image at the other end (not shown in the drawings) of the measuring capillary.

The capillary 3 is also held within the jacket 20 which is connected, in a way not shown in detail, with both housings 26. The space 21, may be filled with liquid.

In an essentially cylindrical bore 27 of the housing 26 a measuring channel 28 is provided which comprises an elastic tube and is held firm in the bore 27. The ends 28^1 of the measuring channel can project at the end surfaces of the housing 26. In the measuring channel 28, the tube 29 is insertable and also comprises an elastic material. The tubes or corresponding sections of tubing can, for example be formed of polyamide or a polyurethane. The measuring channel 28 may also be of a corresponding material. The elasticity of the measuring channel 28 and the tube 29 is, at least in the area of the pressure measuring element 30, such that the internal pressure of the liquid to be measured inside the tube is conveyed to the pressure cell by the tube wall and the measuring channel wall. Thus the use of a tube asymmetrical in cross-section is possible, which in the thicker section of its circumference, marked in Figure 6 with number 29^1, has stronger walls than in the section marked with 29^{11}, here amounting to about $\frac{1}{4}$ of its circumference, which has thinner walls and is consequently more elastic. The thicker section of the circumference 29^1 ensures an adequate stability and prevents the tube from collapsing when drawing in the liquid to be measured. In the recessed position (see Fig. 2) the section of tubing 29^{11} is depressed and lies with initial stress near the measuring channel. Insofar as the pressure gauge 30 according to this working example rests upon the measuring channel, this too is depressed in the area of support, whereupon an adequate pressure conveying surface is created. The external diameter of the actual measuring tube 29 is preferably slightly larger than the internal diameter of the corresponding measuring channel 28. Consequently the pressure in the measuring section 31 is conveyed from the tube to the wall of the measuring channel without the elastic

forces in the tube influencing the measurement.

The tubes 29 can be inserted through the measuring channels to the ends of the capillary. They can at the same time serve as a connecting tube of the capillary to the reservoir unit. The tubes can be expendable items, which are thrown away after the masuring. Consequently the need to sterilize the tubes after their use is eliminated. For another measurement, they will be replaced by new sterile tubes. The measuring capillary manufactured of metal can then be sterilized in the usual way. For the rest, the parts controlling the liquid can be developed as illustrated in the example of Figures 2 and 4.

The pressure gauges 30 are suitably in the form of strain gauges, i.e. semi-conductor elements with piezoelectric effect. The use of strain gauges has the advantage that practically no stretching of the measuring channel occurs and therefore substantially no interference of the measurement by the elasticity of the material of the measuring channel wall occurs.

The working example of Figs. 5 and 6 shows schematically a pressure gauge 30, which has a diaphragm on its underside resting on the measuring channel which is provided with strain gauges. It is located in a recess 32 whose longitudinal axis runs vertical to the longitudinal axis of the bore 27. The measuring elements of the pressure gauge, e.g. strain gauges, rest directly on the external wall of the measuring channel. Instead of this, one could also directly fit, strain gauges or similar on the external wall of the measuring channel. In this case no flattening of the measuring channel in the measuring area is necessary, however on the outer lying reverse side of the strain gauges there is an open space, through which the connection pipes are led. Thus the measuring channel does not come into contact with the medium to be measured and the pressure gauges on the external side of the measuring channel are not contacted by the liquid to be measured. The measuring channels prevent the liquid spreading in the course of time through the tube, from reaching the pressure gauge. With the construction according to Figs. 5 and 6 as against the construction according to Figs. 2 to 4, the space to be filled by the liquid is restricted to the cross-sections of the flow of the capillary, the reservoir unit and the admission and outlet pipes. Dead spaces in the area of the measuring arrangements are avoided. This results in several advantages. The test volume necessary for a measurement is correspondingly reduced. This is particularly of advantage with the determining of flow behaviour of blood, since consequently one can effect measurements immediately with a very small quantity of blood repeatedly taken from the patient, and in this case a return flow of the blood into the vein is no longer necessary. With dead spaces and the edges and angles as a rule present herewith, the coagulation of blood can result. This is avoided with the arrangement of Figures 5 and 6. Furthermore the elimination of the dead spaces facilitates the cleaning and sterilization of the corresponding parts of the device.

WHAT WE CLAIM IS:—

1. A method of determining the fluidity of a liquid, such as of blood or serum, comprising the steps of drawing the liquid from a vessel through a measuring cell comprising a capillary tube into a reservoir unit, thereafter returning the liquid to said vessel through the measuring cell at a flow velocity that remains constant for a given period of time, and measuring the pressure difference which becomes established between the two ends of the capillary tube, the measured liquid being drawn into and expelled from the measuring cell by pump means acting through an interposed buffer liquid, such as an infusion solution, the liquid to be measured being drawn no further than will ensure that the pump means are wetted only by the buffer liquid, and the entire volume of the measuring cell and reservoir unit not filled with the liquid to be measured being filled with the buffer liquid.

2. A method according to Claim 1, in which the result of the measurement of the pressure difference is converted into electrical signals which are fed to a computer.

3. A method according to Claim 1 or 2, in which a programmed control is provided to time the operation of the pump means.

4. A method according to Claim 1, 2 or 3, in which the liquid to be measured is forced through the measuring capillary tube at consecutively different velocities which are each kept constant for predetermined periods of time.

5. A method according to any preceding claim, in which at the end of a measurement fresh buffer liquid is drawn in through a branch supply pipe and the measuring cell and the reservoir unit are flushed out with this buffer liquid.

6. A method according to any preceding claim in which the measuring cell and the reservoir unit are maintained at a constant temperature.

7. Apparatus for performing the method according to any preceding claim, comprising a measuring cell comprising a capillary tube, means connecting the cell to a vessel containing the liquid to be measured and to a reservoir unit, and means for measuring the pressure difference across the capillary tube of the liquid that passes therethrough, the reservoir unit being connected by a pipe line to pump means for drawing in and

returning the liquid to said vessel, the pump means acting through an interposed buffer liquid, such as an infusion solution, and being arranged such that the liquid to be measured is drawn no further than will ensure that the pump means are wetted only by the buffer liquid, the entire volume of the apparatus not filled with the liquid to be measured being filled with the buffer liquid.

8. Apparatus according to Claim 7, in which the reservoir unit includes a tube whose diameter is of the same order of magnitude as that of the measuring capillary tube, and in which the diameters of the said tube and of the capillary tube are greater than the largest diameter of any object suspended in the measured liquid, and the length of the said tube is greater than that of the capillary tube.

9. Apparatus according to Claim 7 or 8, in which pipe connecting means which come into contact with the measured liquid are of polyamide, platinum, or stainless steel.

10. Apparatus according to Claim 9, in which the connection between the capillary tube and the liquid containing vessel, the connection between the capillary tube and the reservoir unit and the connection between the reservoir unit and the pump means for drawing in and returning the liquid each consist of a length of flexible polyamide tubing and the capillary tube and the said tube in the reservoir unit consists of either platinum or stainless steel.

11. Apparatus according to any of Claims 7 to 10, in which the capillary tube and the said tube in the reservoir unit are contained in thermostatically controlled jackets.

12. Apparatus according to any of Claims 7 to 11, in which precision pressure gauges are provided at both ends of the capillary tube for the purpose of determining the pressure difference.

13. Apparatus according to Claim 12, in which the determined pressure differences are converted into electrical signals and are fed to a computer.

14. Apparatus according to Claim 12 or 13, in which the precision pressure gauges are each fitted in a pipe union for joining the end of the measuring capillary tube to the connecting means.

15. Apparatus according to Claim 14, in which the cross section of flow of the passage formed by the pipe union is greater than the cross section of the capillary tube.

16. Apparatus according to any of Claims 12 to 15, in which the pressure gauges are diaphragms provided with strain gauges.

17. Apparatus according to any of Claims 7 to 16, in which the pressure difference measuring means comprise pressure measuring devices at the edge of the flow cross-section of the connecting means at each end of the capillary and are acted upon the pressure of the liquid to be measured.

18. Apparatus according to Claim 17, wherein each pressure measuring device is mounted on the external wall of a measuring channel within which a liquid flow tube is fitted, the tube and the measuring channel each comprising an elastic material conveying the pressure of the liquid.

19. Apparatus according to Claim 18, in which the external diameter of the measuring tube is slightly larger than the internal diameter of the corresponding measuring channel.

20. Apparatus according to Claim 18 or 19, in which the measuring channel comprises a section of tubing which is mounted in a bore in a housing, and the housing has a recess running perpendicular to the axis of the bore, in which recess the pressure measuring device is fixed.

21. Apparatus according to Claim 18 or 19, in which strain gauges are fixed directly onto the external wall of the measuring channel.

22. Apparatus according to any of Claims 18 to 21, in which the tubes at least in the area in which they affect the pressure measuring device within the measuring channel are more elastic than in their remaining area.

23. Apparatus according to any of Claims 18 to 22, in which, for the purpose of replacement, the tubes can be passed through the measuring channels and fixed on the ends of the measuring capillary.

24. Apparatus according to any of Claims 7 to 23, in which on the pipe line leading from the reservoir unit to the pump means a branch is provided for the admission of the buffer liquid.

25. Apparatus according to Claim 24, having a stop valve in the pipe line which valve is located between the reservoir unit and the branch and a further stop valve in the branch.

26. A method of determining the fluidity of a liquid, substantially as described herein with reference to the accompanying drawings.

27. Apparatus for determining the fluidity of a liquid substantially as described herein with reference to the accompanying drawings.

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Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1980.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY
from which copies may be obtained.

1556154 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

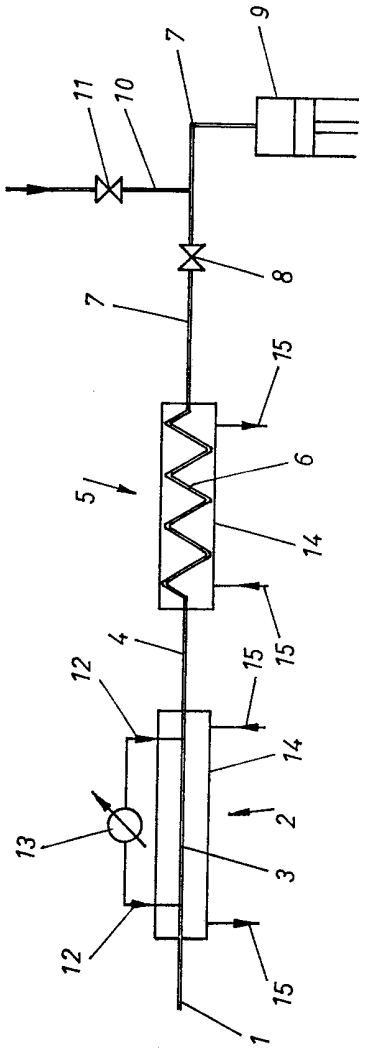

Fig. 1

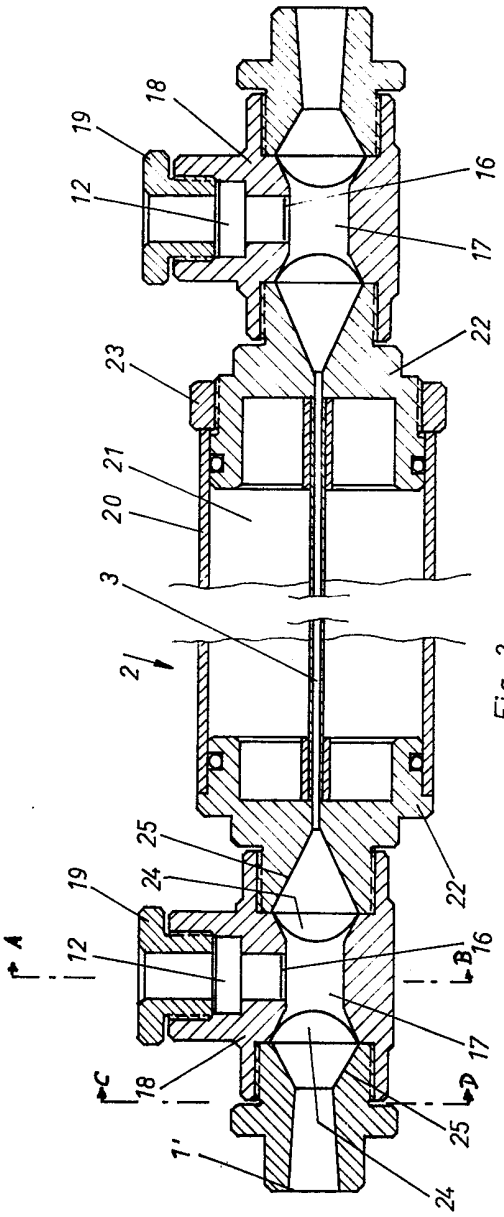

Fig. 2

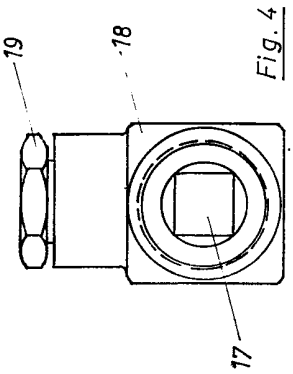

Fig. 4

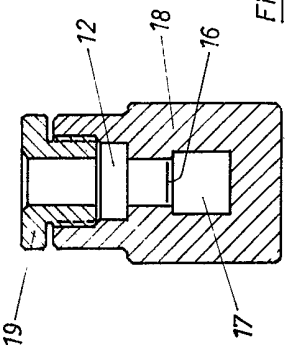

Fig. 3

Fig. 5

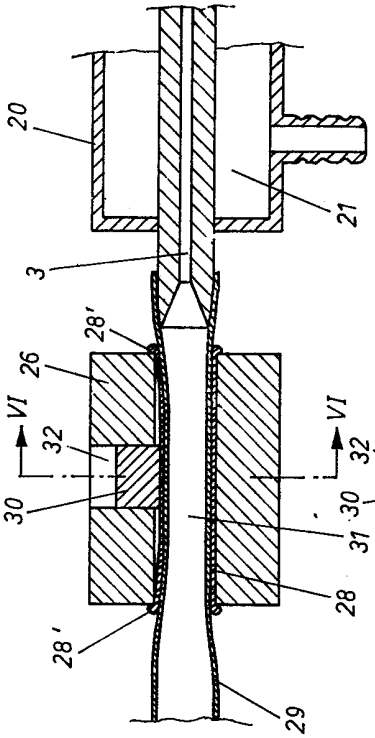

Fig. 6