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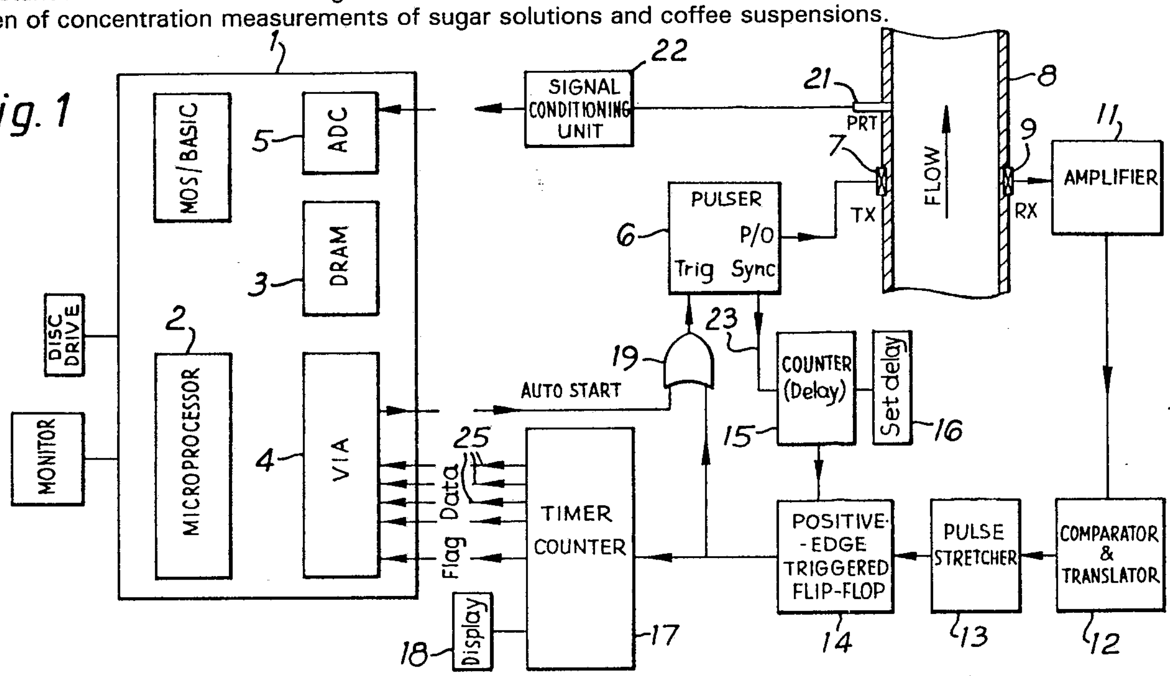
(54) Method and apparatus for on-line concentration measurement of a substance using ultrasonic pulses

(57) There is disclosed a method and appratus for on-line measurement of the concentration of a substance passing through a conduit (8). The apparatus may comprise a pulse generator (6), an ultrasonic transmitter (7), and an ultrasonic receiver (9). The receiver (9) receives an initial electronic pulse and then echoes thereof. Also provided are means (12, 13) for converting each pulse received by the receiver into an electrical pulse, means (14) for detecting the nth echo pulse at the receiver and thereupon initiating another pulse from the pulse generator (6), means (15, 17) for measuring the time delay between a transmitted ultrasonic pulse and the reception of the nth echo thereof to derive a transmission frequency, means (2) for calculating the velocity of sound in the substance under test from said transmission frequency, said time delay, the number of the nth echo and the separation of the transmitter and the receiver, and means (2) for comparing the measured velocity of sound with predetermined values for known concentrations of the substance under test and deriving therefrom the concentration of the substance under test. Examples are given of concentration measurements of sugar solutions and coffee suspensions.

Fig. 1



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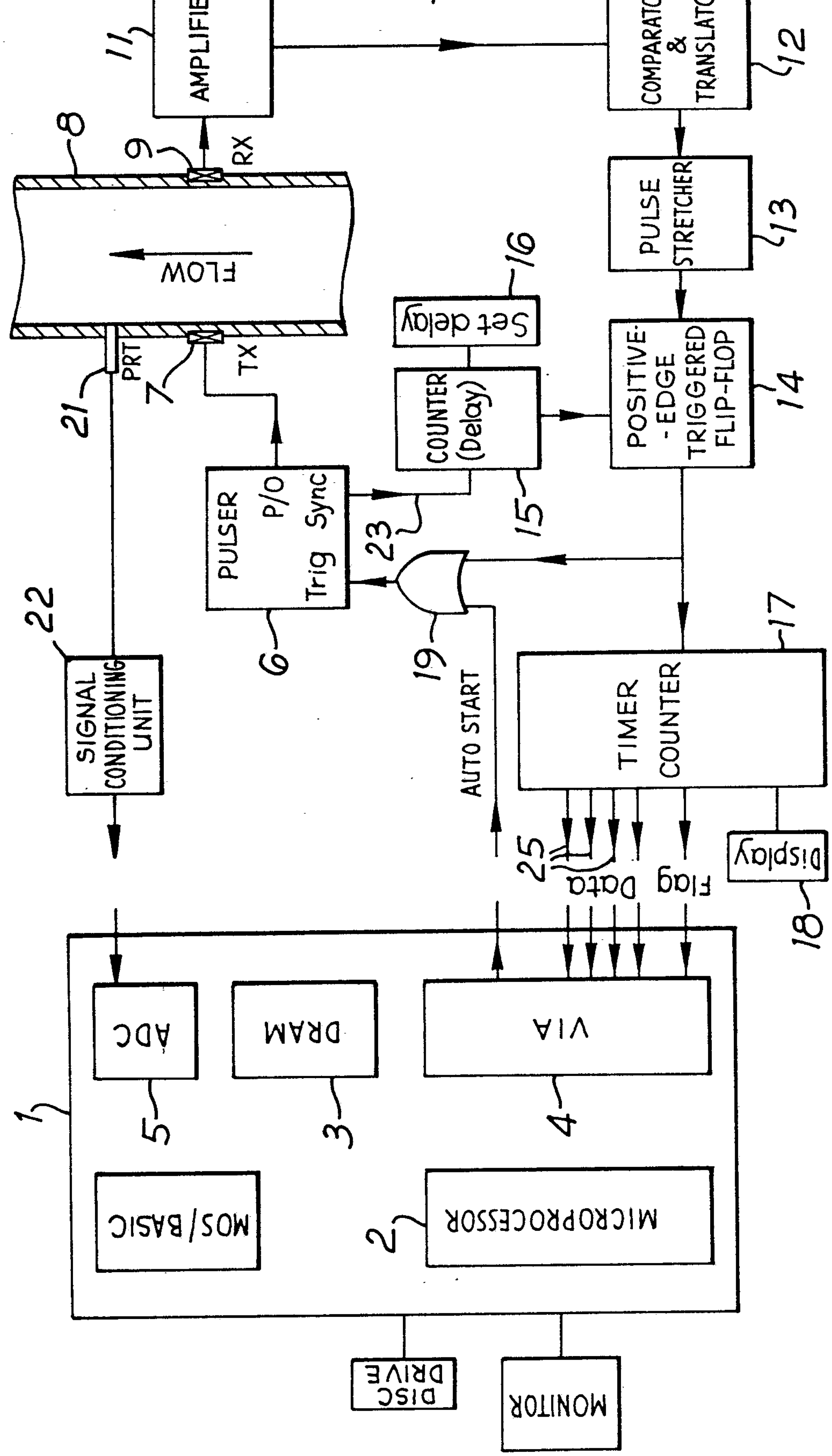


AMPLIFIER
11
COMPARATOR & TRANSLATOR
12
8
9
RX
FLOW
PULSE STRETCHER
13
16
Set delay
PRT
7
TX
21
COUNTER (Delay)
POSITIVE-EDGE TRIGGERED FLIP-FLOP
14
PULSER
P/O
Trig
Sync
23
15
22
SIGNAL CONDITIONING UNIT
6
19
AUTO START
17
TIMER
COUNTER
25
Data
Flag
Display
18
ADC
DRAM
VIA
1
5
3
4
MOS/BASIC
MICROPROCESSOR
2
DISC DRIVE
MONITOR

Fig. 1

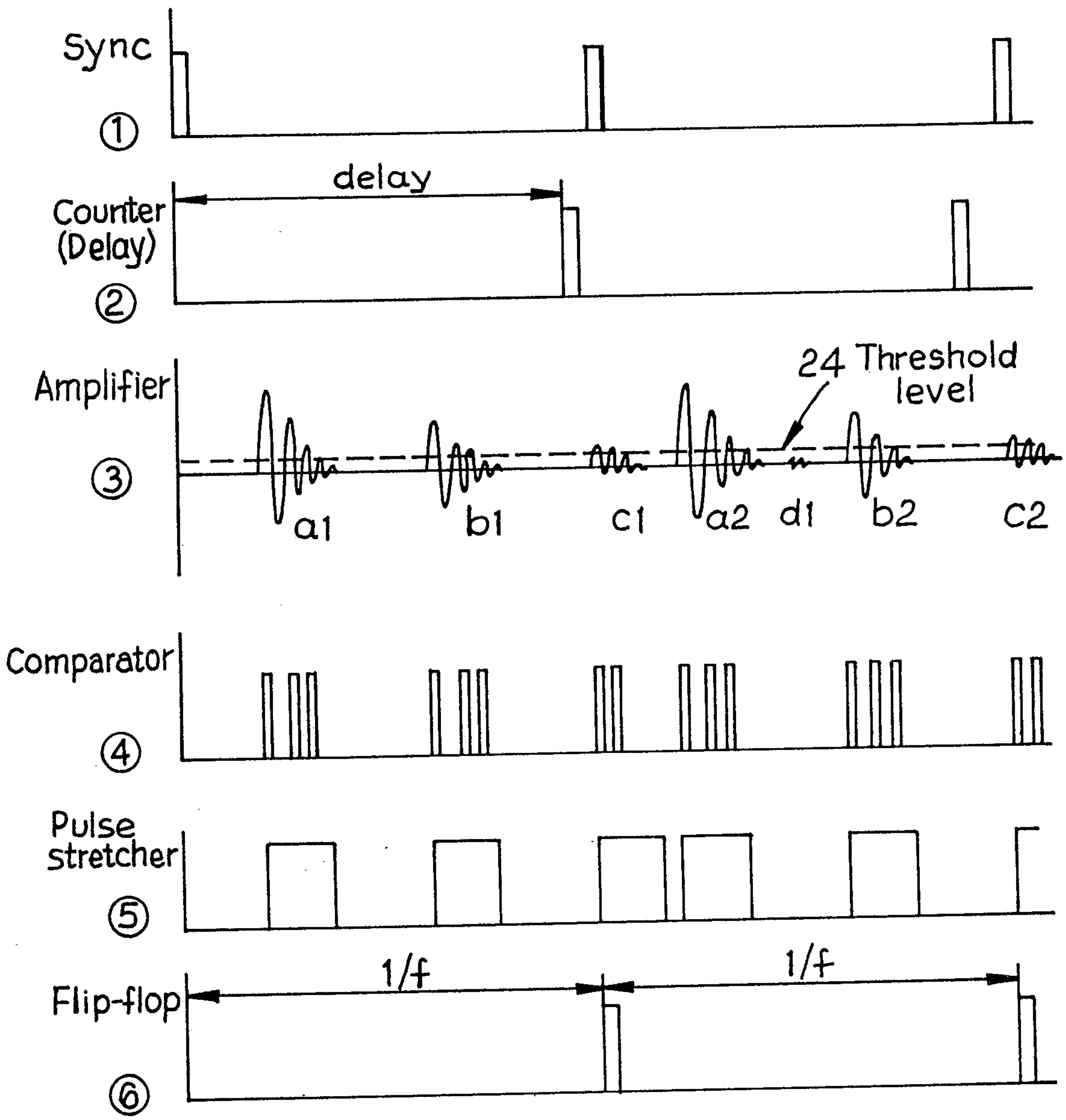

Sync
①
delay
Counter (Delay)
②
24 Threshold level
Amplifier
③
a1
b1
c1
a2
d1
b2
C2
Comparator
④
Pulse stretcher
⑤
1/f
1/f
Flip-flop
⑥

Fig. 2

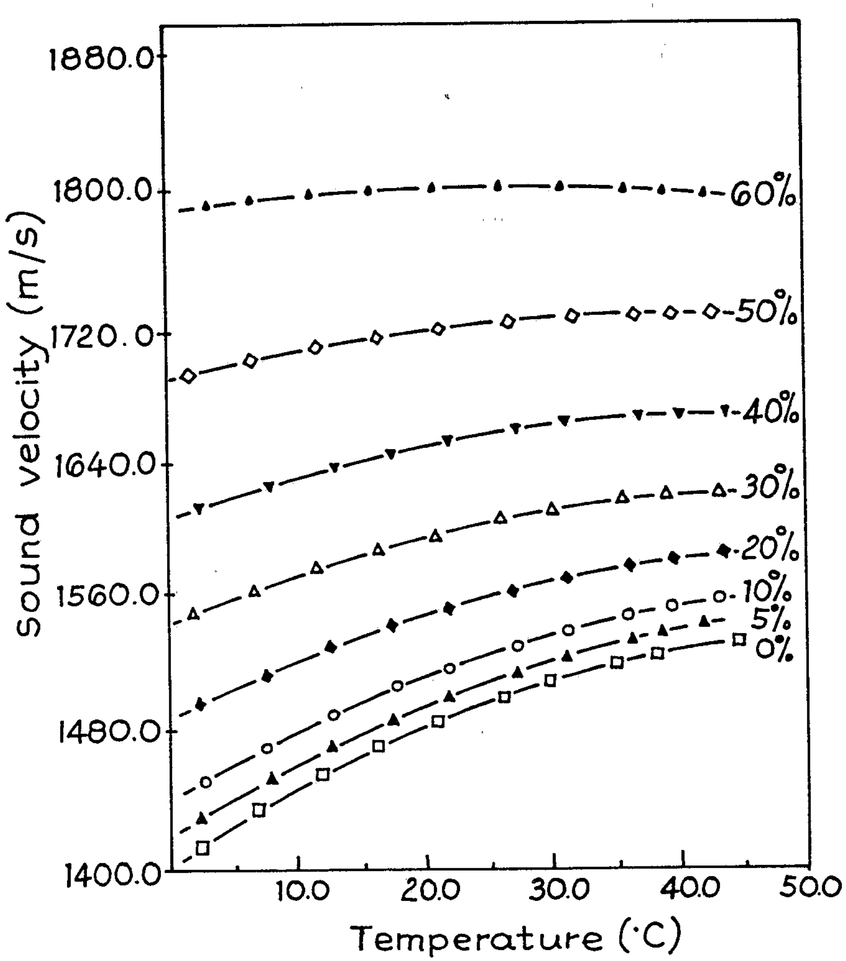


Fig. 3 Sound velocity in sucrose with temperature variable and % sugar concentration (w/w) parameter

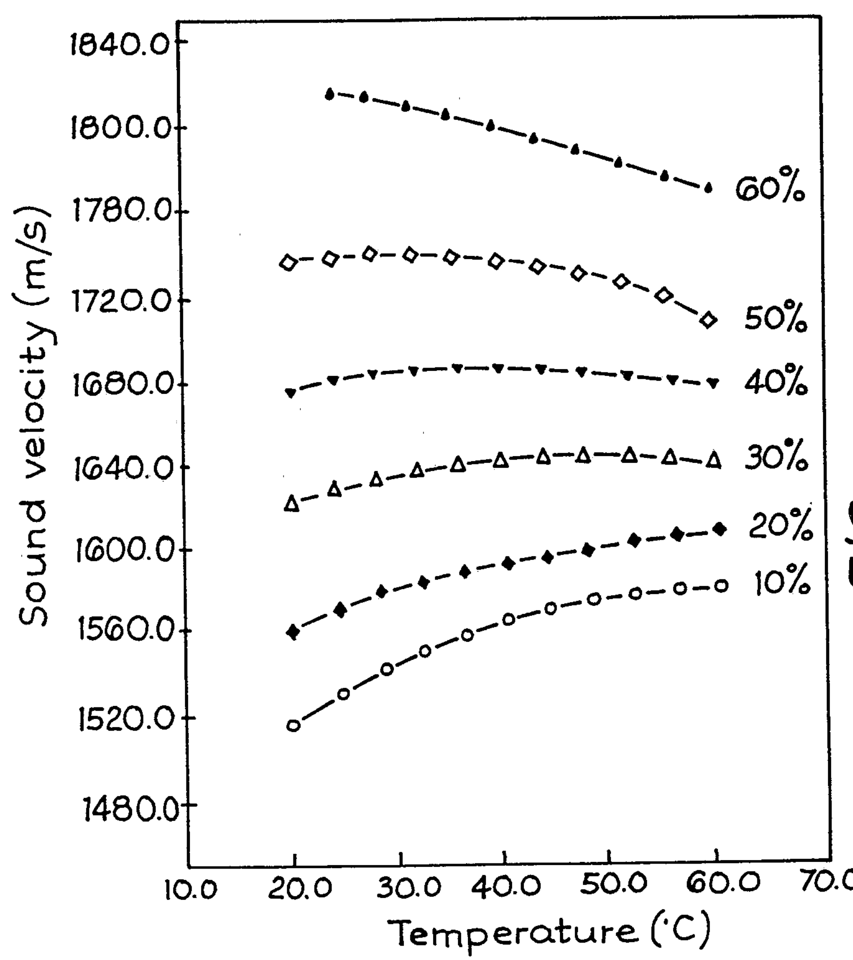
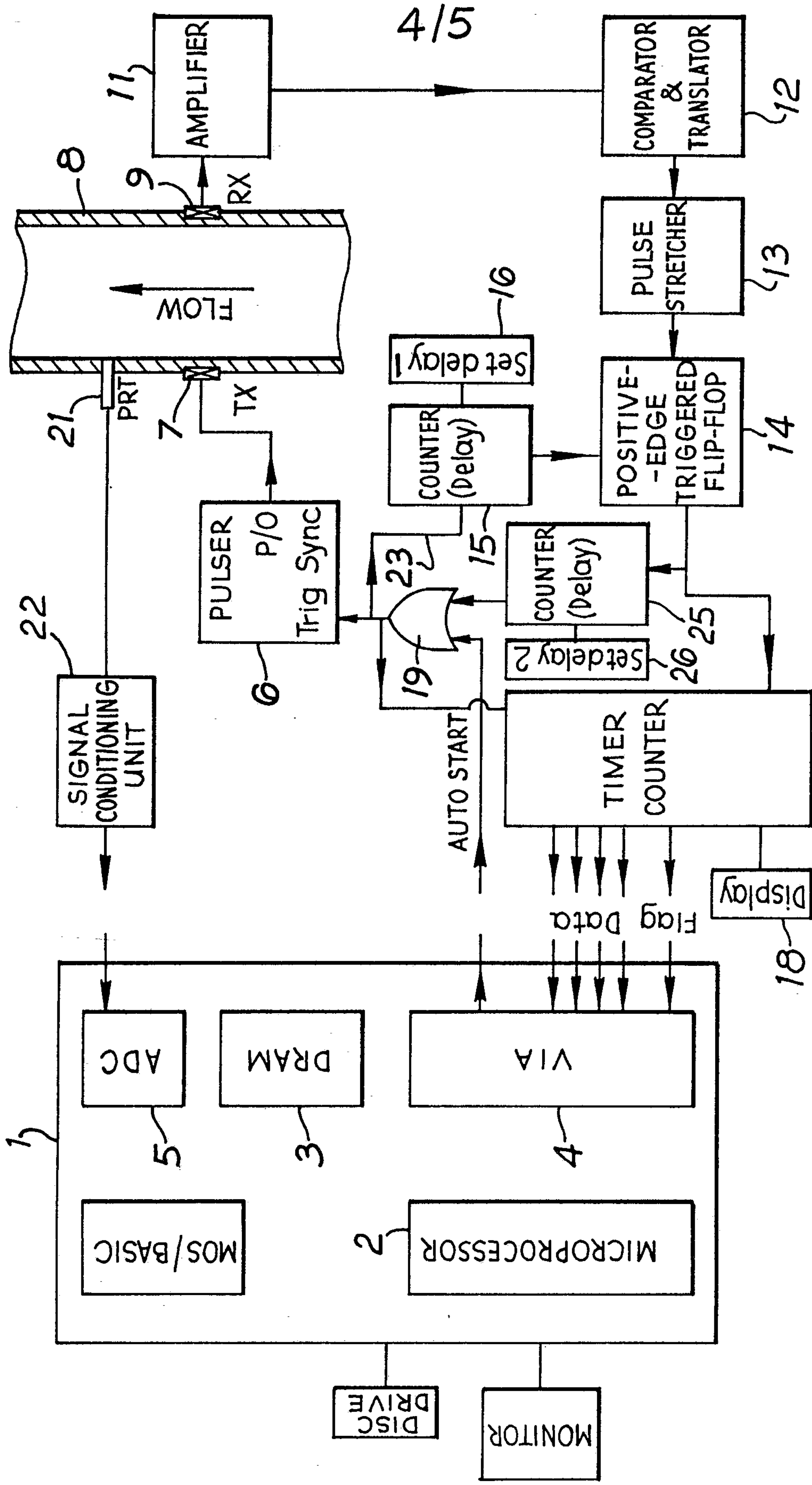


Fig. 4 Sound velocity in coffee suspension with temperature variable and solid contents (% w/w) parameter



AMPLIFIER
11
COMPARATOR & TRANSLATOR
12
8
9
RX
FLOW
PULSE STRETCHER
13
16
Set delay 1
POSITIVE- -EDGE TRIGGERED FLIP-FLOP
14
21
PRT
7
TX
COUNTER (Delay)
15
PULSER P/O Trig Sync
23
COUNTER (Delay)
25
Set delay 2
26
22
SIGNAL CONDITIONING UNIT
6
19
17
AUTO START
TIMER COUNTER
Display
18
Data
Flag
ADC
DRAM
VIA
1
5
3
4
MOS/BASIC
2
MICROPROCESSOR
DISC DRIVE
MONITOR

Fig. 5

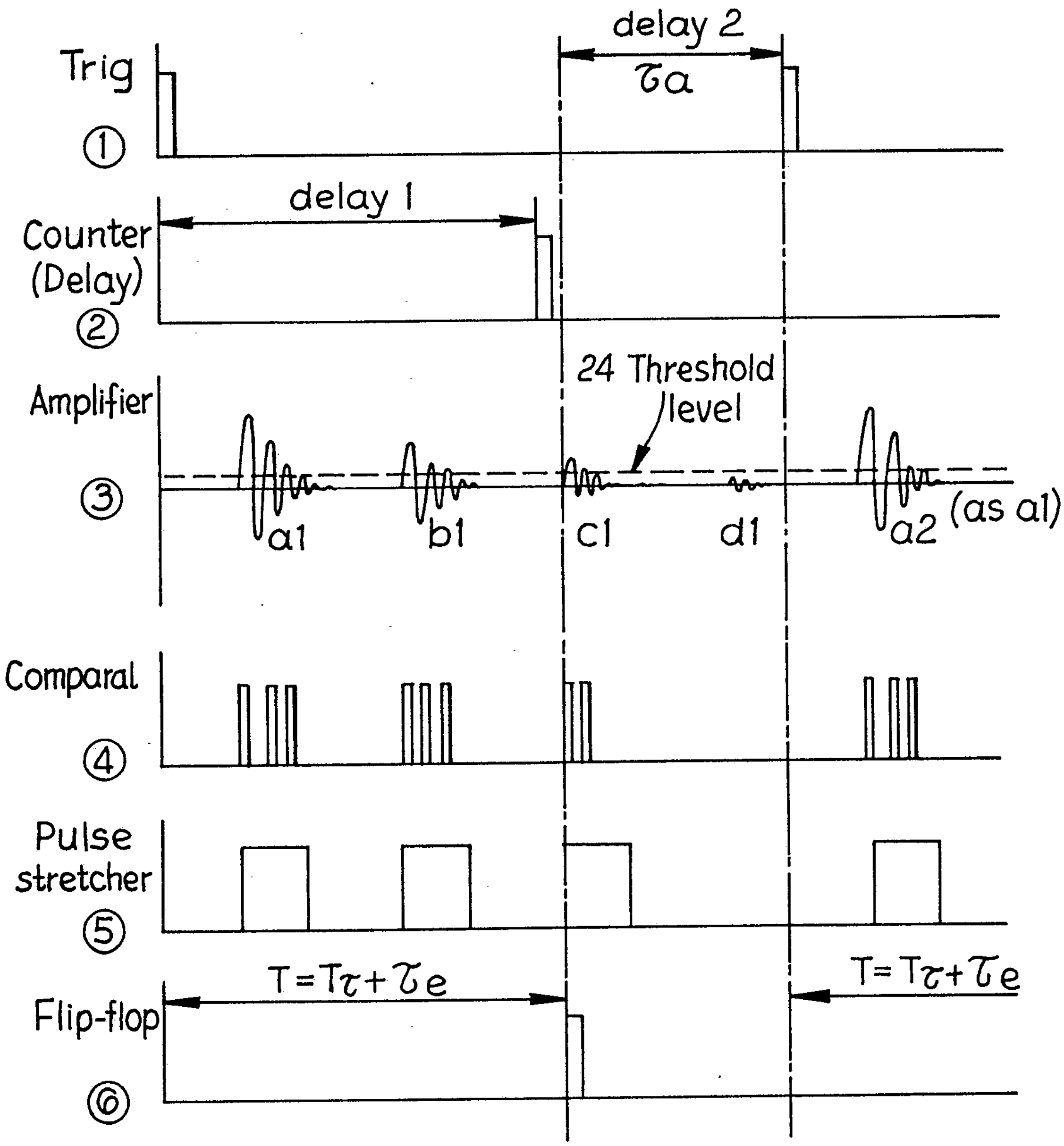

delay 2
τa
Trig
①
delay 1
Counter
(Delay)
②
24 Threshold
level
Amplifier
③
a1
b1
c1
d1
a2 (as a1)
Comparal
④
Pulse
stretcher
⑤
T=Tτ+τe
T=Tτ+τe
Flip-flop
⑥

Fig. 6

SPECIFICATION

Method and apparatus for on-line concentration measurement

This invention relates to method and apparatus for on-line measurement of the concentration of a substance, such as a solution or suspension, flowing through a conduit using ultrasonic techniques.

Solids content of food products is considered to be an important quality indicator in the food industry and has been identified as one parameter which food manufacturers need to monitor and control during product processing. In the chemical industry, the concentration of substances can be important for economical and/or safety reasons.

It is known in both the food and chemical industries to use ultrasonic techniques in measuring the concentration of substances which are static but no reliable method and apparatus for on-line concentration measurement has yet been devised. Thus it is an object of the present invention to provide such a method and apparatus employing ultrasonic techniques and which is capable of measuring concentration to an accuracy which is better than that achieved by present arrangements which typically has a limit of 0.1%.

According to a first aspect of the present invention there is provided a method of on-line measuring the concentration of a substance passing through a conduit comprising the steps of transmitting an ultrasonic signal pulse by pulse into the substance between an ultrasonic transmitter and an ultrasonic receiver disposed on opposed sides of the conduit on a line which is substantially at right angles to the direction of flow of the substance within the conduit, whereby the receiver receives an initial ultrasonic pulse and then echoes thereof, converting each pulse received by the receiver into an electrical pulse, detecting the nth echo pulse at the receiver and using the electrical pulse representative thereof to initiate the transmission of the next ultrasonic pulse from the transmitter, measuring the frequency of transmission of the ultrasonic pulses, measuring the time delay between a transmitted ultrasonic pulse and the reception at the receiver of the nth echo thereof, calculating the velocity of sound in the substance under test from said transmission frequency, said time delay, the number of the nth echo and the separation of the transmitter and the receiver, and comparing the measured velocity of sound with that for known concentrations of the substance under test and deriving therefrom the concentration of the substance under test.

The step of converting each received ultrasonic pulse into an electrical pulse may be carried out using a comparator having a fixed threshold and a pulse stretcher, the electrical pulse thus being a square pulse which lags behind the received pulse by the time which the latter spends below the threshold of the comparator.

According to a second aspect of the invention there is provided apparatus for on-line measurement of the concentration of a substance passing through a conduit, the apparatus comprising a pulse generator, an ultrasonic transmitter connected to the pulse generator, and an ultrasonic receiver, the transmitter and receiver being adapted for mounting on opposed sides of the conduit on a line which is substantially at right angles to the direction of movement of the substance through the conduit, whereby in use the receiver receives an initial ultrasonic pulse and then echoes thereof, means for converting each pulse received by the receiver into an electrical pulse, means for detecting the nth echo pulse at the receiver and thereupon initiating another pulse from the pulse generator, means for measuring the time delay between a transmitted ultrasonic pulse and the reception of the nth echo thereof, means for calculating the velocity of sound in the substance under test from said transmission frequency, said time delay, the number of the nth echo and the separation of the transmitter and the receiver, and means for comparing the measured velocity of sound with predetermined values for known concentrations of the substance under test and deriving therefrom the concentration of the substance under test.

The means converting each received ultrasonic pulse into an electrical pulse may comprise a comparator having a predetermined threshold and operable to produce a plurality of uniform square pulses for each peak of the received pulse of a magnitude greater than the threshold, and a pulse stretcher which converts the plurality of a square pulses from the comparator into a single square pulse of a predetermined width, which pulse lags behind the received pulse by the time which the latter spends below the threshold of the comparator. With the arrangement of uniform pulse stretching, the apparatus is given stability of operation.

The means for detecting the nth echo pulse may comprise a flip flop which receives the output signals from both the converting means and the means for measuring the time delay, whereby the echo pulse next occurring after the delay has timed out is clocked, whereupon the flip flop produces an output signal which is used to trigger the pulse generator to initiate the transmission of the next acoustic pulse. A central processor unit (CPU) may be employed for storing data concerning the velocity of sound in known concentrations of the substance under test and for deriving the actual concentration of the substance at a given instant which may be displayed on a visual display unit (VDU).

It will be appreciated that unless special steps are taken, the temperature of the substance under test will vary with time and it is a preferred feature of the present invention to provide temperature compensation otherwise the accuracy of the measurement of the velocity of sound will be impaired. Thus temperature sensing means may be employed to sense the temperature of the substance under test generally at the point at which the transmitter and receiver are disposed. A signal representative of the sensed temperature is applied to the means for deriving the concentration of the substance under test, which may be a CPU as discussed above, whereby the final readout is compensated for temperature variation.

Preferably, the equation used to derive the concentration C is :

$$C = a + bV + cV^2 + dV^3$$

where V = the velocity of sound in the substance and a, b, c and d are coefficients, determined by calibration, which are dependent on temperature.

In order to ensure that all echos from the immediately preceding transmitted ultrasonic pulse have had time to attenuate completely before another pulse is generated, a further time delay may be employed so as to impart an extra delay in transmitting the next pulse following the measurement of the delay between the generation of the immediately preceding pulse and the nth echo thereof.

A method and apparatus for the on-line measurement on the concentration of a substance in accordance with the invention will now be described in greater detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a first embodiment of the invention,

Figure 2 is a timing diagram useful in explaining the operation of Figure 1,

Figures 3 and 4 are graphs of results obtained with the apparatus of Figure 1,

Figure 5 is a block diagram of a second embodiment of the invention, and

Figure 6 is a timing diagram useful in explaining the operation of Figure 5.

With the exception of the expression for sound velocity in dilute emulsions, no analytical expressions are known from which the velocity of sound in substances such as solutions and suspensions can be predicted from composition and temperature data. Data obtained from sound velocity measurements on aqueous solution have, in the main, been described by equations of the form:

$$VC_T = Voo + \Delta V + \Delta VC + \Delta VC_T \qquad (1)$$

where Voo = 1402.392 m/s is the sound velocity in water at 0°C. A variation on the above equation is used in the present invention to compute the concentration (C) from velocity (V) and temperature (T) measurements i.e.,

$$C = a + bV + cV^2 + d^{V3} \qquad (2)$$

The coefficients a, b, c and d are determined by calibration and are dependent on temperature.

It is clear from equation 2 that the error in % concentration readout as determined by ultrasonic velocimetry is dependent on the accuracy with which both the sound velocity and temperature are determined. The error in % concentration readout is given by the expression

$$\text{error} = \frac{\Delta \text{Verror} + [dV/dt]\,\Delta \text{Terror}}{dV/dC} \qquad (3)$$

where V_{error} and T_{error} are the sound velocity and temperature measurement errors. The temperature coefficient dV/dT and concentration coefficient dV/dC are properties of the substance and as such are not dependent on the method of measurement.

A number of sources of error need to be considered and compensated for when contemplating making sound velocity measurements on flowing substances. Errors in sound velocity measurements arise from:

i) Mass motion of the substance.

ii) Variations in the attenuation characteristics of the substance due to changes in composition and temperature.

iii) Extraneous effects resulting from scattering and the presence of echoes from previous excitations.

The error in measured sound velocity due to mass motion can be minimised by arranging for the ultrasonic path to be normal to the direction of flow. A reduction in the effect of the other sources of error on measured sound velocity can be achieved by reducing the pulse repetition frequency and maximising the ratio of acoustic transit time and delay time. The delay time is defined as the interval between the leading edge of the received pulse crossing zero and the pulse being detected by a timing circuit. This is achieved in the present sing-around sound velocimeter by delaying retriggering of a pulser until detection of the arrival of an nth echo as will be described hereinafter.

Referring now to Figure 1 of the accompanying drawings, this shows in block diagram form an ultrasonic solution concentration monitor which comprises a central processing unit (CPU) 1 embodying a microprocessor 2 a memory 3, a versatile interface adaptor (VIA) 4, and an analogue-to-digital converter (ADC) 5. The monitor further comprises a sound velocimeter having a pulse generator 6 connected to a transmitter 7 which is attached to one side of a pipe 8 or conduit through which flows the solution under test. A receiver 9 is mounted on the pipe 8 opposite the transmitter 7, these two components being on a line which is generally orthogonal to the direction of flow of the solution through the pipe. The receiver 9 is connected to an amplifier 11 which in turn is connected to a comparator 12. The output of the comparator 12 is connected to a pulse stretcher 13. A flip-flop 14 receives the output from the pulse stretcher 13 and the output from a counter 15 which can be set at 16 to provide a predetermined delay. The CLOCK output from the flip flop 14 is connected to a frequency counter, fitted with a display 18, and as one input to an OR gate 19. The frequency counter 17 has a plurality of BCD (binary coded decimal) output lines 25 which are connected to the CPU 1 via the VIA 4.

The monitor further comprises a temperature sensor in the form of a platinum resistance thermometer 21 which is connected to the CPU 1 via a signal conditioning unit 22 the voltage output of which is digitised by the CPU and converted to degrees Celsius.

In operation, the transmitter 7 and receiver are attached to opposed sides of the pipe 9 in an acoustic conductive manner and the separation thereof noted. The instrument is calibrated for the solution under test (which may be a suspension or other substance) by putting into the memory 3 values for the parameters a, b, c and d of equation 2 which have been determined by calibration on solutions with known concentrations over a range of temperatures, the sample concentrations and temperature range being appropriate to the respective ranges likely to be experienced with the solution under test.

To commence monitoring, a control (not shown) on the CPU 1 is operated, whereupon a pulsed signal is transmitted via the VIA 4 on a second input to the OR gate 19 and this triggers a short fast electrical pulse from the pulse generator 6 to the transmitter 7 which is a transducer which converts that pulse into an acoustic pulse. The acoustic pulse is transmitted across the pipe 8 towards the receiver 9 from which it is reflected back towards the transmitter 7 and then back to the receiver and so on until it undergoes 100% attenuation. Thus the receiver 8 receives the initial pulse and then echoes thereof. Simultaneously with triggering the output pulse from the pulse generator 6, the output from the OR gate also triggers a SYNC pulse (line 1 of Figure 2) from the pulse generator which is applied on a line 23 to the counter 15 to initiate the timing of the delay which has been previously set therein using the control 16.

The initial acoustic pulse and each echo thereof received at the receiver 9, which is also a transducer, is converted to an electrical pulse and amplified by the amplifier 11 (line 3 of Figure 2) and applied to the comparator 12 (line 4 of Figure 2). The output from the amplifier 11 is an antennuating sine wave with wave a1 being the initial pulse and b1, c1 and d1 the echoes thereof as seen in line 3 of Figure 2. The comparator 12 produces a squared pulse for each peak of a1, b1, etc., above a predetrmined threshold level of the comparator which is indicated at 24 in line 3 of Figure 2. In order to stabilise the operation of the monitor, the pulse stretcher 13 produces a squared pulse of a predetermined width from the pulses of the comparator for a given received pulse, which pulse lags behind the related received pulse by the time which the latter spends below the comparator threshold lever.

When the counter 15 times out, a signal is applied to the flip flop 14 by the counter which clears the flip flop so that the next pulse from the pulse stretcher 13 is clocked and sent to both the OR gate 15 and the frequency counter 17. The pulse on the one input to the OR gate triggers another pulse from the pulse generator 6 to the transmitter 7 and triggers a SYNC pulse to the counter 15, whereby the cycle is repeated. The pulse to the frequency counter 17 serves to enable the latter to calculate the frequency of transmission of the acoustic pulses (known as the sing-around frequency f) which is displayed on the display 18 and applied to the VIA 4. The frequency f is measured to ± 1Hz over 1 second periods and is available on the BCD output lines 25 every 1.2 seconds in this embodiment.

Thus the nth (in this example the second) echo of an acoustic pulse is detected and it is not until the nth pulse has been detected that the next acoustic pulse is triggered. This is to eliminate any ambiguity in the detected pulse or echo. The order of the delay effected by the counter 15 in tens of microseconds.

Throughout the triggering of the acoustic pulses, the thermometer 21 continuously measures the temperature of the solution, this data being transmitted to the CPU via the ADC 5.

The sound velocity V in the solution under test is related to the sing-around frequency f as follows:

$$V = \frac{[(2n-1)L]f}{1 - df} \qquad (4)$$

where d, n and L are the electronic delay (counter 15) plus the time which the amplified received pulse spends below the comparator threshold level, the number of echoes, and the effective transducer separation, respectively. The delay time d and effective path length (2n−1)L are obtained by measuring the temperature dependence of the sing-around frequency f in distilled and de-aerated water and using the equation for sound velocity in water.

The microprocessor 2 of the CPU 1 computes the % concentration C from the sound velocity measurements and temperature measurments using equation 2 for which the parameter a, b, c and d have previously been stored in the memory 3.

One application of the present invention for monitoring and maintaining the sugar content of soft drinks during processing within very tight tolerances which is of paramount importance in maintaining quality and reducing costs. The results of tests on sugar solutions are given below to illustrate the correlation between % concentration, sound velocity V and temperature T in sucrose.

Another application is for monitoring solids content of coffee suspensions during manufacture of instant coffee to optimise the extraction, evaporation and spray drying processes. The results of tests on certain types of instant coffee suspensions covering the % solids content and temperature ranges found in the manufacturing process are given below.

The tests on sugar and coffee suspensions were carried out off line using a modified version of the on-line transducer attachment. The test-cell was filled with the suspension under test and immersed in a water bath for temperature control. Figure 3 shows the variation of sound velocity with temperature for water and sugar solutions (% sugar concentration 5 to 60%). Figure 4 is a similar plot for the coffee suspensions. The velocity of sound in both sugar and coffee suspensions is seen to increase with solids content. The curves exhibit the characteristic shape for aqueous solutions, i.e. sound velocity increases with temperature to a maximum then decreases with further rises in temperature. The peak in sound velocity is seen to occur at lower temperatures as the solids content is increased.

Table 1 below gives the expected error in % concentration readout for sugar and coffee suspensions when using the ultrasonic concentration monitor of the present invention to make the measurements. The expected error values, calculated using equation 3, are seen to be lower than the target limit of 0.1%

Table 1: Expected error in % concentration readout for sugar and coffee suspensions
Experimental details
Transducers separation = 35mm
Transducer resonant frequency = 2MHz
Echo number 2 used in the measurements. Calibration for path length (2n−1)L and delay time d using the equation for sound velocity in water.
(2n−1)L = 0.104975 ± 0.000014 m   d = 1.58 ± 0.02μs
Approximate sing-around frequency f = 14000Hz
ΔC_{error} = 0.1 m/s ΔT_{error} = 0.1°C
% concentration of suspension determined by oven drying method (vacuum oven at 70°C for 24 hours)

Concentration (%w/w)	Temperature °C	Sucrose dV/dT (m/s/°C)	Sucrose dV/dC (m/s/%)	Sucrose C_{error} (%)	Coffee Dv/dT (m/s/°C)	Coffee dV/dC (m/s/%)	Coffee C_{error} (%)
	20	2.87	3.70	0.10	3.24	4.37	0.09
10	30	2.01	3.93	0.08	2.29	4.04	0.08
	40	1.55	2.75	0.09	1.49	3.96	0.06
	20	1.69	4.79	0.06	1.19	5.59	0.03
30	30	1.36	3.48	0.08	0.91	4.65	0.04
	40	0.72	4.39	0.04	0.53	4.42	0.03
	50	*	*	*	0.04	3.91	0.03
	20	0.99	7.43	0.03	0.05	6.88	0.02
50	30	0.44	6.66	0.02	0.05	5.29	0.02
	40	0.16	6.41	0.02	-0.28	5.13	0.01

It will be seen that the present invention is based on the concept of using the sing-around method of measuring the velocity of sound in a substance but adapted so as to provide a much greater accuracy of measurement and such that a practicable and reliable on-line measurement is possible. This represents a significant advance in the art in as much as the concentration of substances can be monitored, and hence controlled, during a process so that the uniform concentration can be achieved. Thus any criticality in this respect, be it for commercial, safety or other reasons is readily satisfied.

The invention was made with four basic requirements in mind and these are all met by the present method and apparatus, the requirements being:

1. To achieve an accuracy of concentration measurement better than 0.1%.
2. To compensate, when necessary, for changes intemperature.
3. To provide a stable readout.
4. To make the apparatus simple to calibrate and use.

Referring now to Figures 5 and 6, these illustrate an alternative embodiment of the present invention which is basically similar to that of Figures 1 and 2, the only difference being that a further time delay by way of a counter 25 is employed, this counter being provided between the output of the flip flop 14 and the corresponding input to the OR gate 19. The counter 25 is adjustable at 26. All of the other components of this second embodiment are similar to those of the first embodiment and have been allocated like reference numerals.

The timing diagram of Figure 6 illustrates the operation of the second embodiment. As before, the pulse generator 6 is first triggered via the VIA 4 by the microprocessor 2 and applies a short, fast pulse to the transmitting transducer 7 and synchronised pulses to the timer counter 17 (start counter timer) and delay counter 15 (to start countdown from a preset delay time value, typically of the order of 10s μs). The transducer 7 converts the pulse into an acoustic wave which travels back and forth between the transmitting and receiving transducers 7, 9 before being completely attenuated. Each time the acoustic wave strikes the receiving transducer it is converted into an electrical signal. The received pulse is then amplified at 11 before being fed into the comparator 12. The comparator 12 and pulse stretcher 13 convert each received echo into a square pulse which lags behind the received pulse by the time which the latter spends below the comparator threshold level 24. The outputs from the delay counter 15 and the pulse stretcher 13 are fed into the flip flop 14. The flip flop 14 selects the n th echo which immediately follows the end of delay countdown period of counter 15 and generates a pulse which stops the timer counter 15 and triggers the further delay counter 24 to start a countdown from a preset delay time value. This delay time is typically of the order of 1000s μs to allow for all echos from the previous cycle to attenuate completely. At the end of this countdown period, the counter 25 generates a pulse which triggers the pulser 6 and starts the cycle again.

The counter 17 measures the elapsed time T_τ between a pulse striking the transmitting transducer and detection of the arrival of the nth echo at the receiving transducer. The elapsed time T_τ includes the pulse transit time through the suspension and delay time τ, which includes the electronic delay and the time which the amplified nth echo spends below the comparator threshold level 24. The sound velocity in the suspension under measurement is related to the measured time T_τ as follows:

$$C = (2n-1)L/(T_\tau - \tau)$$

where n and L are the number of echoes and the effective transducer separation, respectively.

There is an inherent variation in the delay time τ_a from the pre-set value which affects the "singing" frequency of the system. For this reason the elapsed time $T = T_\tau + \tau_e$ between the triggering of the transmit pulse and the detection of the arrival of the nth echo at the receiver (see Figure 6) is measured. T is a more pertinent and accurate indicator of variations of sound velocity in the medium than the "singing" frequency of the system.

It will be appreciated that the method and apparatus of the present invention is non-intrusive or non-invasive and can be used to make solids content or concentration measurements of any substance which is sufficiently "transparent" to ultrasound radiation.

CLAIMS

1. A method of on-line measuring the concentration of a substance passing through a conduit, the method comprising the steps of transmitting an ultrasonic signal pulse by pulse into the substance between an ultrasonic transmitter and an ultrasonic receiver disposed on opposed sides of the conduit on a line which is substantially at right angles to the direction of flow of the substance within the conduit, whereby the receiver receives an initial ultrasonic pulse and then echoes thereof, converting each pulse received by the receiver into an electrical pulse, detecting the nth echo pulse at the receiver and using the electrical pulse representative thereof to initiate the transmission of the next ultrasonic pulse from the transmitter, measuring the frequency of transmission of the ultrasonic pulses, measuring the time delay between a transmitted ultrasonic pulse and the reception at the receiver of the nth echo thereof, calculating the velocity of sound in the substance under test from said transmission frequency, said time delay, the number of the nth echo and the separation of the transmitter and the receiver, and comparing the measured velocity of sound with that for known concentrations of the substance under test and deriving therefrom the concentration of the substance under test.

2. A method according to claim 1, wherein the step of converting each received ultrasonic pulse into an electrical pulse is carried out using a comparator having a fixed threshold and a pulse stretcher, the electrical pulse thus being a square pulse which lags behind the received pulse by the time which the latter spends below the threshold of the comparator.

3. A method according to claim 1 or 2, and comprising the further step of delaying the triggering of a next ultrasonic pulse by a predetermined time period of following receipt of the nth echo of the immediately preceding transmitted pulse.

4. Apparatus for on-line measurement of the concentration of a substance passing through a conduit, wherein the apparatus comprises a pulse generator, an ultrasonic transmitter connected to the pulse generator, and an ultrasonic receiver, the transmitter and receiver being adapted for mounting on opposed sides of the conduit on a line which is substantially at right angles to the direction of movement to the substance through the conduit, whereby in use the receiver receives an initial ultrasonic pulse and then echoes thereof, means for converting each pulse received by the receiver into an electrical pulse, means for detecting the nth echo pulse at the receiver and thereupon initiating another pulse from the pulse generator, means for measuring the transmission frequency of the transmitted ultrasonic pulses, means for measuring the time delay between a transmitted ultrasonic pulse and the reception of the nth echo thereof, means for calculating the velocity of sound in the substance under test from said transmission frequency, said delay time, the number of the nth echo and the separation of the transmitter and the receiver, and means for comparing the measured velocity of sound with predetermined values for known concentrations of the substance under test and deriving therefrom the concentration of the substance under test.

5. Apparatus according to claim 4, wherein the means for converting each received ultrasonic pulse into an electrical pulse comprises a comparator having a predetermined threshold and operable to produce a plurality of uniform square pulses for each peak of the eceived pulse of a magnitude greater than the threshold, and a pulse stretcher which converts the plurality of square pulses from the comparator into a single square pulse of a predetermined width, which pulse lags behind the received pulse by the time which the latter spends below the threshold of the comparator.

6. Apparatus according to claim 4 or 5, wherein the means for detecting the nth echo pulse is a flip flop which receives the output signals from both the converting means and the means for measuring the time delay, whereby the echo pulse next occurring after the delay has timed out is clocked, whereupon the flip flop produces an output signal which is used to trigger the pulse generator to initiate the transmission of the next acoustic pulse.

7. Apparatus according to any of claims 4 to 6, and further comprising a central processor unit for storing data concerning the velocity of sound in known concentrations of the substance under test and for deriving the actual concentration of the substance at a given instant.

8. Apparatus according to any of claims 4 to 7, and further comprising display means for displaying the concentration of the substance under test at a given instant.

9. Apparatus according to any of claims 4 to 8, and further comprising temperature sensing means operable to sense the temperature of the substance under test generally at the point at which the transmitter and receiver are disposed.

10. Apparatus according to claim 9, wherein a signal representative of the temperature sensed by the temperature sensing means is applied to the means for deriving the concentration of the substance under test.

11. Apparatus according to any of claims 4 to 10, wherein the equation used to derive the concentration C of the substance under test is:

$$C = a + bV + cV^2 + dV^3$$

where V = the velocity of sound in the substance and a, b, c and d are coefficients, determined by calibration, which are dependent on temperature.

12. Apparatus according to any of claims 4 to 11, wherein the means for measuring the time delay between a transmitted ultrasonic pulse and the nth echo thereof comprises a counter.

13. Apparatus according to claim 12, wherein the counter is adjustable, whereby the number of the detected echo may vary.

14. Apparatus according to any of claims 4 to 13 and further comprising further delay means operable to delay, by a predetermined time period, the transmission of the next ultrasonic pulse following receipt of the nth echo of the immediately preceding transmitted pulse.

15. Method and apparatus for on-line measurement of the concentration of a substance passing through a conduit substantially as herein particularly described.

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