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GB 2278679 A GB 2264556 A
US 4977314 A US 4957363 A
US 4626927 A US 4548500 A

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INT CL[7] G01N 15/02 15/14
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(54) Abstract Title

Detector assembly for detecting liquid-borne particles individually

(57) Assembly comprises a scattering zone made of transparent plates or column (11) with wide area, a pulsed illuminator (12) an optical matrix detector (15). The gap between the walls of the plates is so narrow that it allows the particles to flow only in a single file. The width of the beam is comparable to the size of the particles. As the particles traverse the bean, their scattered light towards the detector defines a range of solid angles. As the coming rays within these angles are received by different members of the matrix in the detector, and since differently sized/ shaped particles would emit their scattered light at different range of solid angles, the detector is able to identify size, and rough shape of individual particles traversing the beam. The assembly may have a second detector on the opposite side of the scatter zone, tuned to detect the type of the particles from their flourescent light.

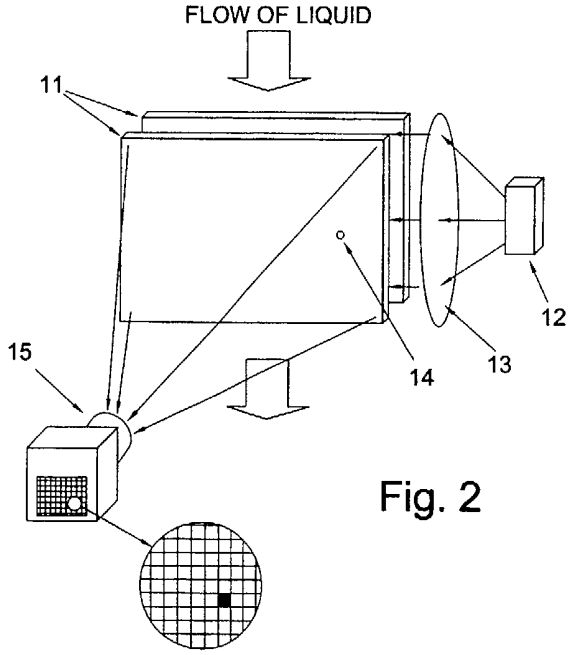


Fig. 2

GB 2 376 070 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

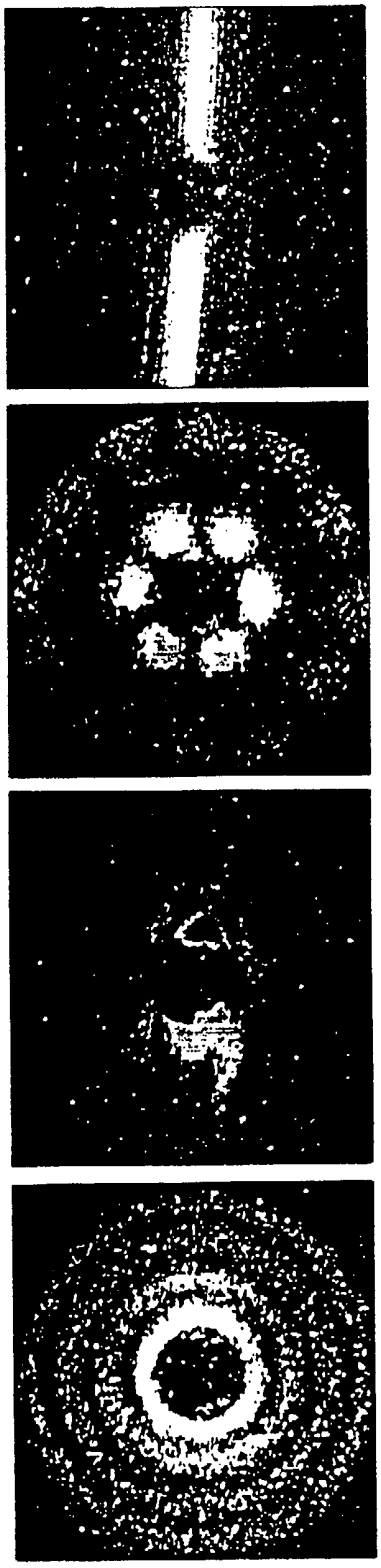


Fig. 1

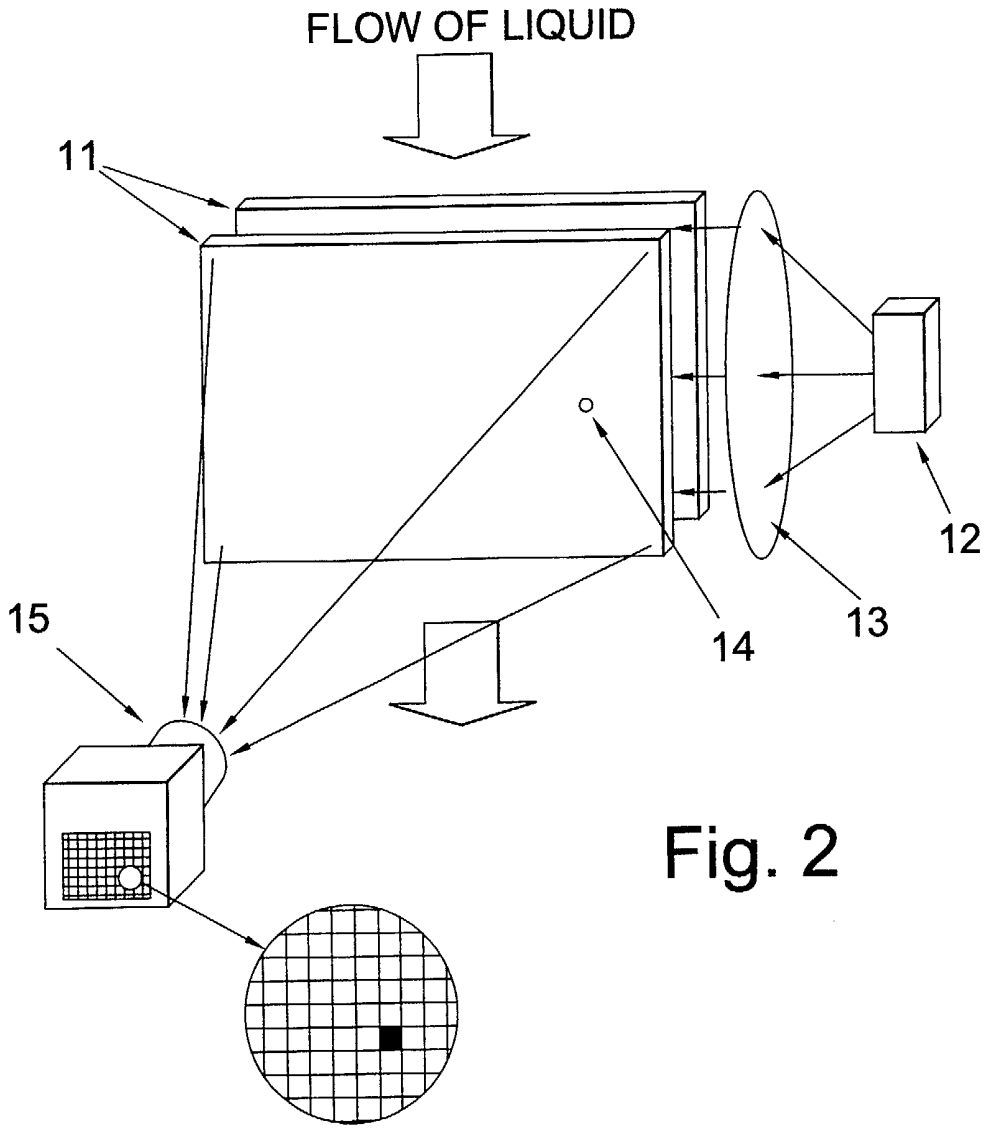


Fig. 2

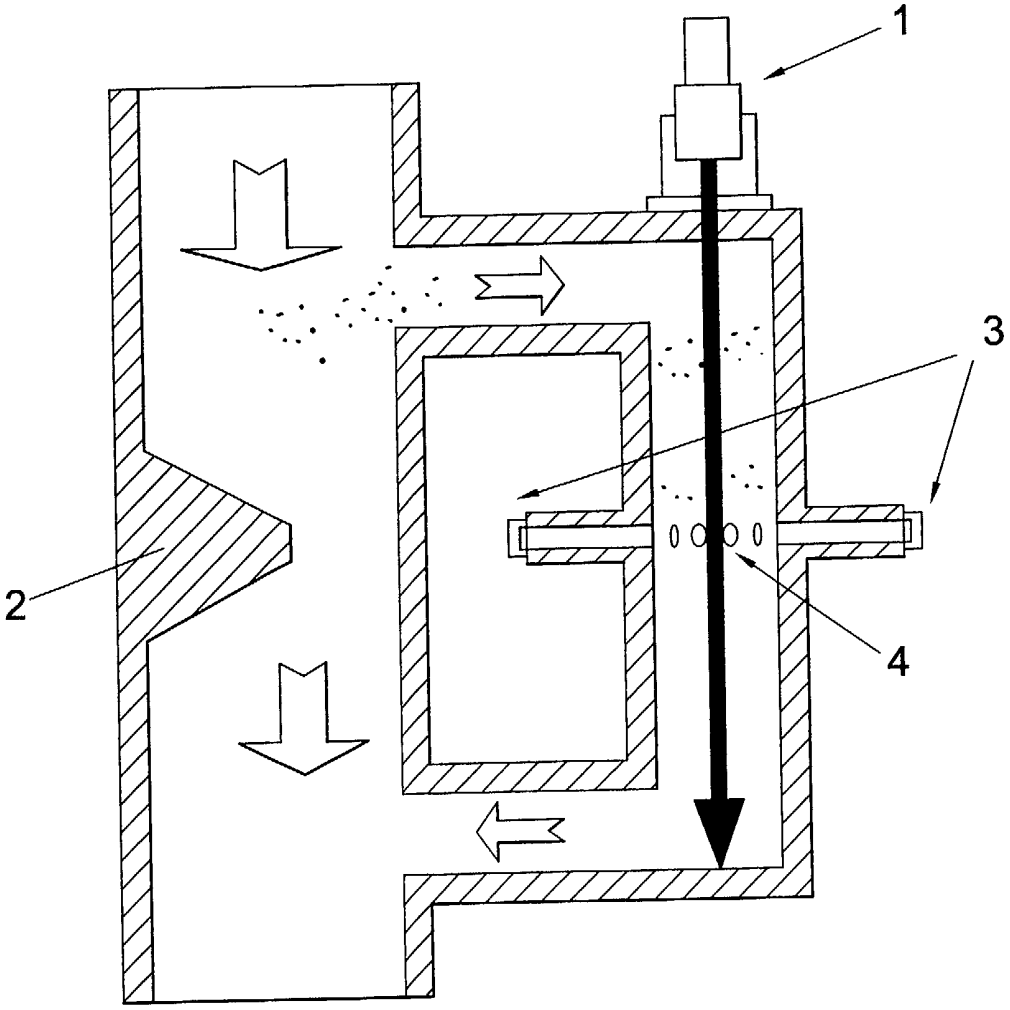


Fig. 3

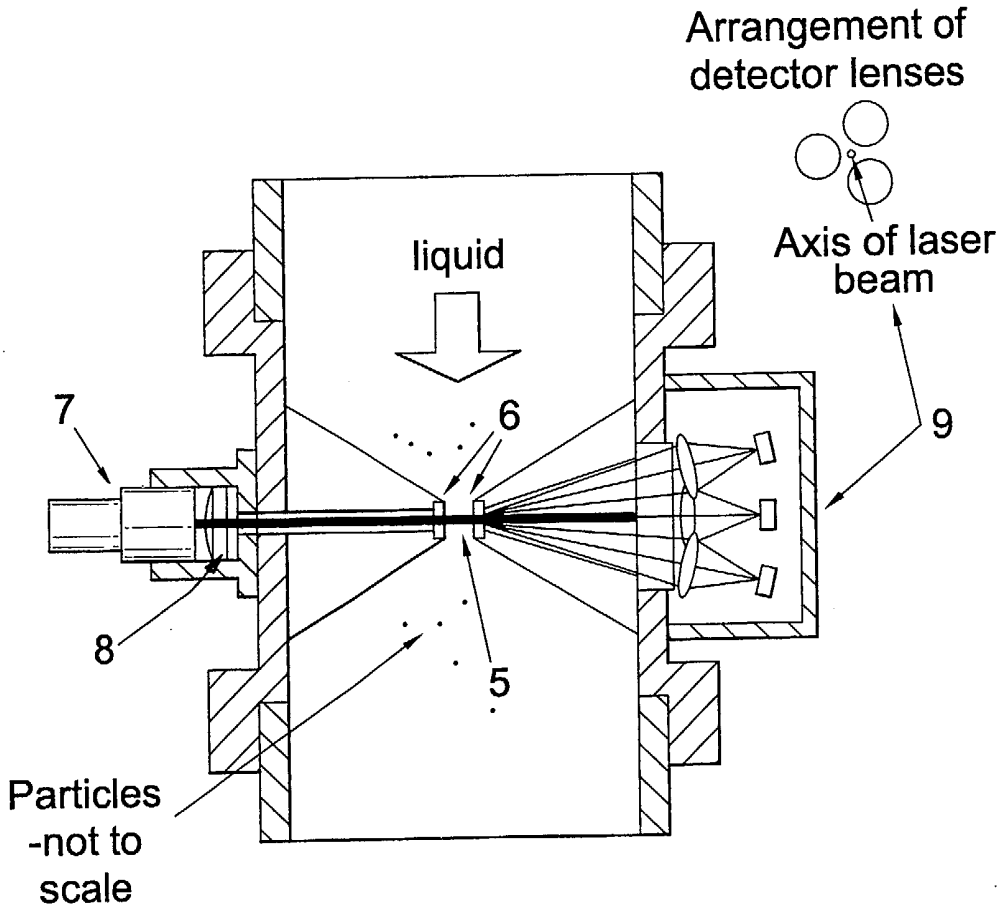
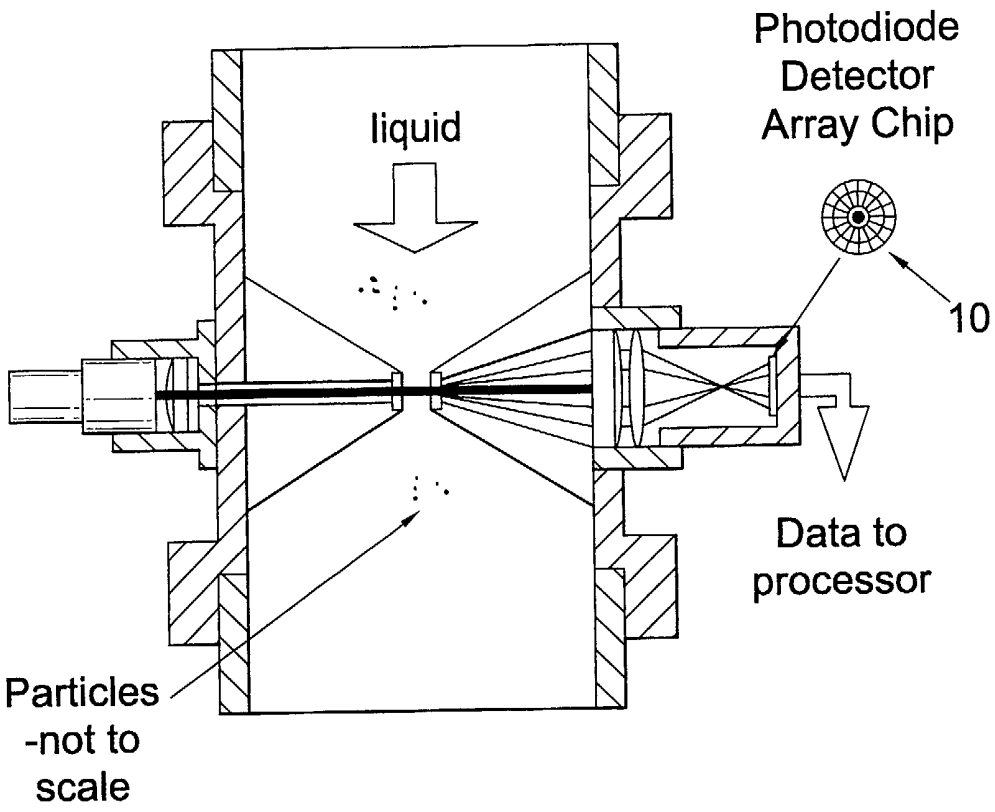

Arrangement of detector lenses
Axis of laser beam
liquid
7
6
9
8
5
Particles -not to scale
liquid

Fig. 4


Photodiode
Detector
Array Chip
liquid
10
Data to
processor
Particles
-not to
scale

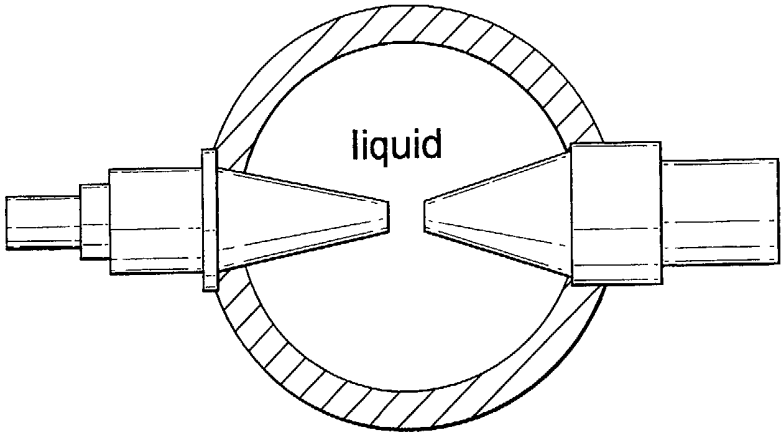

liquid

Fig. 5

Detection and Characterisation of Liquid-Borne Particles

Field of the Invention

This invention relates to methods and apparatus by which particles, and suitably microparticles, typically in the size range from 0.3 μm to 100 μm, which are carried in a liquid suspension, may be rapidly detected and characterised. The present invention makes it possible to differentiate various types of particle carried in liquid suspension, and has widespread application in clinical, industrial, and environmental monitoring fields.

Background to the Invention

The measurement and characterisation of liquid-borne particles (which in the broadest description may include bubbles of gas) is of importance in a number of fields. In some cases the particles are a natural and desirable constituent of the suspension, such as, for example, red and white cells in blood, and the measurement of the concentrations of each type of particle forms the basis of important physiological tests. In many other cases the particles may constitute undesirable contamination which may cause degradation or malfunction of the system of which the suspending liquid forms a part. Examples include: the presence of solid, liquid, or air (bubbles) carried in suspension in hydraulic liquids, which can compromise the efficiency of the hydraulic system and, in some cases, may be a precursor of catastrophic system mechanical failure, (such as in helicopter gearboxes and control systems); the presence of biological organisms in water, especially bacterial regrowth in the outputs of water processing plants supporting domestic and industrial consumption; the presence of particulates in highly purified liquids, such as those for use in medical intravenous applications or in industrial processing where particulates are to be avoided (as in microelectronics or pharmaceutical manufacture); the presence of particles of rust (or other solids) and droplets of water carried in fuel (such as petroleum based aviation fuel, petrol, diesel, etc.), which can cause engine misfire or eventual failure. This list is not exhaustive but serves to illustrate the wide range of situations where the detection of liquid-borne particulates is important. Moreover, in many cases it is important to establish the nature of the particulate contamination and differentiate between particles which may be tolerated and those which represent serious contamination. For example, in the case of processed water for domestic consumption,

solid particulate such as sand or rust particles are not normally a hazard, whilst bacterial cells or other microorganisms may well be dangerous to health. In the case of liquid fuels, liquid particulates (i.e: immiscible droplets) may be tolerated as they would not normally block filters or fuel-injection jets, whilst solid particulates cannot be tolerated. There are several existing methods of investigating the particulate content of a liquid suspension, some of which may be carried out on-line. The simplest approach is to filter some of the suspension onto an appropriate filter medium and observe the trapped particles using, for example, optical or electron microscopy. This has the disadvantage of being an off-line measurement process not suited to continuous monitoring, and is unable to determine the presence of immiscible liquid droplets within the suspension.

Another common method of counting liquid-borne particles is via an instrument which is based on the 'electro-zone' measurement method. In this method, first developed by Coulter (Coulter Electronics Inc., USA), liquid-borne particles are forced singly through a minute orifice which is marginally larger than the largest particles to be measured. Immersed within the suspension on either side of the orifice are two electrodes at different electrical potentials. As the particle passes through the orifice the resistive path between the electrodes is perturbed and this may be detected as pulse in the current flow between the electrodes. This type of instrument is widely used for counting blood-cells in suspension and for providing particle concentration measurements in colloidal suspensions. In general however, the instruments are primarily particle counters, and do not provide unambiguous differentiation between, say, solid particles, immiscible droplets, and bubbles of air or gas. They are also subject to blockage if the maximum particle size is greater than that of the orifice. (For this latter reason, they are often employed in. situations where the nature of the particulate suspension is already known, such as in blood or other physiological fluids.)

Many manufacturers produce optical scattering instruments for measuring particles in liquids. These instruments broadly fall into two classes, those which illuminate a suspension of particles, and those which illuminate individual particles. In both cases, size spectra and concentration. figures for the particle suspension may be produced. An example of the former type of instrument is the Malvern Mastersizer (Malvern Instruments Ltd., Malvern, Worcester, UK), in which the particle suspension is illuminated with a broad collimated beam of light and the light diffracted by the suspension is analysed using a concentric ring detector array aligned with the beam axis. The signal

levels from each ring may be deconvolved to reveal a particle size spectrum. Since multiple particle illumination occurs, no shape information relating to individual particles is achievable using this type of instrument. An example of the single particle counter sizer is the Microcount from HIAC Royco Inc. (Maryland, USA). This instrument illuminates a narrow liquid flow with a focused laser beam in such a way that particles pass singly through the beam. Light diffracted by each particle is collected by a single detector, and the magnitude of the signal pulse from the detector may be related to a first order to particle size. Again, no information relating to particle morphology or shape is recorded (all particles are essentially considered to be spherical), and it is therefore not possible to differentiate between particle types except on the basis of size.

One instrument which can provide shape and size information, though not on-line, is the Galai DSA-1O from Galai production Ltd., Migdal Haemek, Israel. This instrument uses stroboscopic illumination to acquire 'still' images of a particle suspension using a solid-state camera system. Image processing software then determines the sizes and shapes of the particles pictured in the captured image. It is essentially a variant of the type of image processor system which may be used on optical images from filter-captured particles and is thus not capable of real-time or continuous monitoring of particle suspension flows.

Spatial Laser Scattering Profiles

In theory, the detailed spatial intensity distribution of light scattered by individual particles (the scattering profile) contains information relating to inter alia the particle's size, its shape, and its orientation with respect to the incident illumination. This is illustrated in Figure 1 which shows the spatial distribution of light scattered from variously-shaped individual particles. In each case the scattering relates to the forward direction, i.e: below 35° to the incident beam direction. Similar scattering patterns may be recorded covering higher scattering angle ranges. The images were recorded using a laser scattering instrument fitted with a high-speed intensified charge-coupled~device (CCD) camera to record the light scatter data. The radial and azimuthal variations in scattered light intensity provide the information by which particle size, shape, and orientation may be assessed. The invention reported here is aimed at exploiting this dependency of the light scatter pattern on particle size and shape with a view to discriminating and sizing, in real-time, different types of particle which may be found in a liquid suspension. Additionally, by the use of ultraviolet light to illuminate the particle, a separate measurement may be

made of particle fluorescence and this can be of further value in, for example, discriminating biological from non-biological particles or detecting microscopic droplets of oil contamination in water.

As previously mentioned, most optical scattering instruments used for particle counting and/or sizing, rely on collecting the scattered light with a single discrete detector. Such instruments cannot provide information on particle shape, and indeed normally assume that all measured particles are spherical when ascribing a size value to them. When a small number of discrete detectors are used, each collecting light over a different solid angle within the sphere of scattering around the particle, some shape as well as size information is obtainable. This principle is embodied in a number of patented instruments which may be considered as prior art: (Portable Particle Analysers, Ludlow, I. K. and Kaye P H. European Patent EP 0 316 172, July 1992; 'Particle Asymmetry Analysers. Ludlow, I. K and Kaye, P. H. European Patent EP 0 316 171, Sept. 1992. These patents describe instruments for the measurement and characterisation of particles in air or other gaseous medium. In particular, spherical particles (such as droplets) may be readily distinguished from non-spherical particles since the former will scatter circularly or randomly polarised light equally to detectors arranged azimuthally about the beam axis whilst the latter will rarely do so. The same physical principles apply to the measurement of liquid borne particles, though the implementation of the principles is necessarily different because of the nature of the liquid medium. The new implementation is described in the remainder of this application.

Liquid-borne Particle Measurement

Whenever single particle scattering is required from a particle suspension, it is necessary to create a 'scattering volume'; i.e: a region within the suspension which, statistically, is not likely to contain more than one particle at any instant and through which the particles will pass in single file and at potentially high rates. In the case of monitoring airborne particles (as described in the above cited prior art) the scattering volume is achieved by delivering the air containing the particles at high speed through a narrow tube and thence through a laser beam directed at right-angles to the sample airflow. The dimensions of the tube are normally such that the entire diameter of the airflow is within the width of the intercepting laser beam. The scattering volume is then defined as the volume of intersection of the airflow with the laser beam. If particle concentrations in the flow are high, it is often necessary to reduce the diameter of the sample airflow to a point where

delivery through a narrow tube is impractical because of particle losses on the tube walls. In this case, it is usual to ensheath the particle laden air with filtered particle-free air and to aerodynamically focus these combined flows such that the effective diameter of the sample flow containing the particles is reduced to a satisfactory dimension without particle losses. This technique is applied in most commercial optical particle countersizer instruments.

However, this approach is not ideal for liquid-borne particles for two reasons: firstly, the aerodynamic focusing of the combined flows causes the flows to accelerate. This acceleration of the gaseous medium causes the particles to experience a drag force.

For liquid droplets in air, the surface tension of the droplets is normally much greater than this drag force, and therefore the droplets remain essentially spherical and may be differentiated from other particles by the light scattering properties of this unique shape. However, for liquid droplets in another liquid (in which they are immiscible), the interfacial tension forces at the droplet surface may be very small compared to the viscous drag forces which the droplet may experience in. an accelerating flow, and the droplet will readily deform. The deformed droplet will then scatter light in. an irregular way and it may not be distinguishable from other non-spherical particles.

Secondly, when a beam of light such as that from a laser passes through a pure medium such as air or a liquid, light is scattered out of the beam by small variations in the density (and hence in the refractive index) of microscopic volumes of the medium (brought about as a result of the constant thermal motion of the atoms or molecules making up the fluid). In air or other gas, this scattering is not normally significant and long optical path-lengths through the medium (such as in delivering the beam of light to the scattering volume) can be employed. In liquid, however, this is not the case as the background scattering is proportionally much greater than for air. The use of long path-lengths would therefore significantly compromise attempts to measure the scattering intensities from single suspended particles. An alternative means of establishing a scattering volume is therefore required for the case of liquid-borne particle flows.

In some cases the concentration of particles of interest in a liquid can be very low, such as for example, in detecting pathogenic biological particles in drinking water supplies. In such cases the concentration of such particles may be only 1 per 10 litres or less. When

using the methods described above, the scattering volume may be so small that the time taken to deliver a sufficient volume of liquid through the scattering volume in order to detect a statistically significant number of particles may be unacceptably long. In such cases a larger 'scattering volume' must be used. However, as the scattering volume increases in size, so does the potential level of background scatter and fluorescence from the volume of suspending liquid being illuminated. Often, this background scatter can dominate over the scatter or fluorescence signal from the particle within the liquid volume, and so an alternative approach must be adopted.

Summary of the Invention

The present invention generally provides means of establishing an optical scattering volume within a liquid flow such that particles carried in suspension in the liquid may pass through the volume and in doing so, may scatter light to an arrangement of optical detector elements whose outputs may be used to estimate particle size and in some cases may be used to estimate both the size and shape of the particle.

According to one aspect of the present invention there is provided a detector assembly for detecting liquid-borne particles which comprises:

(i) a scattering zone;

(ii) means for illuminating the liquid-borne particle stream within the scattering zone;

(iii) an optical detector adapted to intercept and collect a portion of the light scattered by each particle passing through the illuminating beam; and

(iv) data processing means adapted to capture and process the signals from the optical detector for each particle traversing the illuminating beam, wherein the optical detector has a matrix of optical detector elements, the scattering zone defines a large scattering volume that is suitably a thin sheet or column of wide area that is illuminated and the optical detector/camera views the wide area of the scattering volume.

Advantageously the light source is a pulsed light source.

Suitably the light source is a source of ultraviolet light and the optical detector is adapted to detect fluorescent light.

Preferably a second optical detector is provided on the opposite side of the scattering zone to said optical detector and one of said optical detector and said second optical detector is arranged to collect the scattered light and the other, the longer wavelength fluorescent light from the particle(s).

Suitably the illumination source is directed along or edge-on to the liquid flow, with the optical detector viewing face-on to the liquid flow.

Advantageously at the scattering zone the liquid flows sandwiched between transparent sheets or more preferably as a 'free column' such as that delivered vertically downwards from an orifice, not constrained by walls.

According to a further aspect of the present invention there is provided a detector assembly for detecting liquid-borne particles which comprises:

(i) a scattering zone;

(ii) means for illuminating the particle stream within the scattering zone;

(iii) an optical detector adapted to intercept and collect a portion of the light scattered by each particle passing through the illuminating beam;

(iv) data processing means adapted to capture and process the signals from the optical detector for each particle traversing the illuminating beam,

wherein the light source is a source of ultraviolet light and the optical detector is adapted to detect fluorecent light.

According to a yet further aspect of the present invention there is provided a method for detecting liquid-borne particles which comprises:

providing a detector assembly as claimed in any preceding claim;

directing a liquid to be tested to flow though the scattering zone;

illuminating the liquid within the scattering zone; and

observing the signals from the optical detector to detect the presence of a particle in the liquid.

Suitably the scattering zone is illuminated in pulses, the frequency and duration of the light pulses being arranged such that the volume of liquid in the scattering zone is replaced by 'new' liquid in the period between light pulses, so that all of the liquid passing through the scattering zone undergoes illumination at some time.

Brief Description of the Drawings

Preferred embodiments of the present invention will now be more particularly described, by way of example, with reference to the accompanying drawings, wherein:

Figure 2 is a schematic isometric view of a detector assembly of the preferred embodiment of the invention;

Figure 3 is a schematic diagram of a detector assembly for detecting liquid borne particles;

Figure 4 is a schematic diagram of an alternative optical detector array to the detector array of the detector assembly of Figure 3;
and

Figures 5 is a schematic diagram of a yet further alternative optical detector array to the array of the detector assembly of Figure 3.

Description of the Preferred Embodiment

Reffering to Figure 2, this shows a detector assembly which employs a large scattering volume viewed by a charge coupled device (CCD) camera or similar optical detector15 having a matrix of optical elements. In one embodiment, the scattering volume is defined between two transparent plates 11. The liquid is constrained to flow between these plates and is confined laterally by two further transparent walls (not shown) at the side edges of the plates. The plates may be typically 8cm by 10cm in area, and separated by 0.5cm. To one side edge of the plates 11 is the illumination source 12. This could be a continuous source of light but the preferred light source is a pulsed light source such as a Xenon flash lamp.

The light from the source 12 is collimated by suitable optics 13 and delivered into the liquid volume between the plates 11. The light is constrained to the region between the plates 11 by total internal reflection. Thus the whole of the liquid volume between the plates is illuminated by the light pulse, and this defines the scattering volume. The

frequency of the light pulsation is arranged such that the volume of water between the plates 11 is replaced by 'new' water in the period between light pulses, so that all of the water passing between the plates undergoes illumination at some time. If at the instant of the light pulse a particle 14 is present in the scattering volume between the plates, it will scatter light in all directions, some of which will not be constrained by total internal reflection and will pass outside the plates. This is true for both scattered light and, if the light source 12 contains sufficiently short wavelengths, particle fluorescent light.

The measurement of the degree of fluorescence of a particle can be used to aid classification of that particle, especially in discriminating between biological particles such as bacteria, and non-biological particles such as mineral dust or other inorganic material which, in general, fluoresce more weakly. The fluorescent data may be recorded by illuminating the particle at a suitable wavelength, normally in the ultraviolet. A single continuous wave ultraviolet laser or Xenon discharge lamp (suitably optically filtered to remove visible wavelengths) or similar source may be used. If the light output from the source can be suitably collimated and focused, the source may be used to produce simultaneously both the spatial scattering data and the fluorescence data, the latter being recorded with an additional suitably-placed optical detector capable of collecting fluorescent light from the particle.

The light must first pass through an optical filter to remove the original ultraviolet wavelengths and allow through only the longer fluorescence wavelengths. Alternatively, separate optical sources may be used providing their beams are spatially coincident at the measurement space through which the particles flow. In the latter case a practical arrangement would incorporate a continuous wave visible laser to generate spatial scattering data and a pulsed ultraviolet laser, triggered by passage of the particle through the visible beam, to generate fluorescence data. The determination of parameters relating to the shape, size, and fluorescent properties of the scattering particle thus affords an effective means of discriminating particle classes such as biological and non-biological particles.

As illustrated in Figure 2, the whole area of the scattering volume is imaged onto a CCD camera 15 or similar that is face-on to the plates 11. This type of camera has at its focal plane a semiconductor device containing a matrix of many individual optical detector elements, or pixels, suitably at least tens by tens, preferably hundreds by hundreds and

typically 1000 by 800 pixels. Thus each pixel is observing only a small area of the scattering volume, typically 0.1mm square. This has the advantage that the background scatter signal generated by the suspending liquid and received by each pixel is very small compared to the total background scatter from the whole scattering volume. Thus, whilst all pixels will receive an equal amount of this background scatter, one pixel, i.e: that which views the location of the scattering particle, will additionally receive light scattered by the particle. Because the background scatter signal is small the scatter signal from the particle will be detectable.

Similarly, if the pulsed light source is a Xenon flash lamp suitably optically filtered to allow only the ultraviolet component of its output to enter the liquid, then the particle will not only produce UV scattered light which may be detected, but may also produce fluorescent light. Again, the liquid itself may fluoresce so the method just described of using a CCD camera means that the fluorescence from the particle will be detectable over and above the background fluorescence from the liquid in the immediate vicinity of the particle and viewed by the same pixel. By using a second camera on the opposite side of the plates 11 to the first camera and using appropriate optical filtering on both cameras, one camera can be arranged to collect the scattered light and the second, the longer wavelength fluorescent light from the particle. Thus, for any particle within the scattering volume, a measure of the scattered light, which is related to particle size, and the particle fluorescence, which is related to particle material, may be recorded. This method does not allow measurement of the spatial distribution of light scattered by the particle, so particle shape information is not obtainable.

If the light source is pulsed at 100Hz, which is achievable with Xenon flash lamps, then the total volume of liquid which can be scanned for particles is approximately 100 times the scattering volume, ie: approximately 4 litres per second. In the case for example, of analysing drinking water for biological organisms, this is a sufficiently large throughput to allow a minimum of several organisms per minute to be detected, a statistically significant detection rate. In such an example, the numbers of non-biological particles present in the water may be much greater than the number of biological particles, and the two particle types could be counted, sized (by virtue of the magnitude of the scatter signal), and differentiated (by virtue of the differences in fluorescence produced by the two particle types). Note that the camera must also be capable of collecting 100 images per second, though modern electronic cameras are capable of this.

The method just described could equally be applied to different geometries of scattering volumes. For example, the illumination source could be directed along the liquid flow as in Figure 3, with the camera viewing from the side. Alternatively, the liquid itself may be a 'free-column' such as that delivered vertically downwards from an orifice. The illumination light will be contained within the column by total internal reflection, and the scattered and/or fluorescent light generated by the particle will escape through the surface of the liquid so as to allow detection to the side of the column. This method has the advantage of avoiding fouling of optical surfaces which can occur when in prolonged contact with liquids. In all these cases, an effective method of rapidly analysing the particulate content of large volumes of liquid is provided.

Referring now to Figure 3, in this example of liquid borne particle detector assembly, a collimated beam of light from a laser such as a diode laser 1 is directed along the axis of a pipe through which the particle laden liquid is forced to flow by virtue of a restriction 2 of the pipe carrying the principal liquid flow. Arranged in a plane orthogonal to the laser beam axis is a set of optical detectors 3, each one of which has an aperture 4 which limits the field of view of the detector to a small element of the beam path. Each detector views the same element of the beam path but from a different angle. The intersection of the laser beam with the field of view of each detector defines the scattering volume. Only particles within the scattering volume will scatter light which can be received by the detectors. If a particle carried by the liquid, happens to have a trajectory which lies coincident with the beam, it will pass through the scattering volume and cause a pulse of scattered light to be received by each detector. If the particle is spherical, such as an immiscible droplet, and the polarisation of the laser beam is random or circular, then the light flux to each detector will be the same. If the particle is non-spherical, then the light fluxes received by the detectors would normally be unequal. Recording of the signal levels from the detector will therefore allow the discrimination between particles on the basis of their shapes, such as spherical, fibrous, irregular cubic, etc.

The total amount of light scattered to the detectors will be a function of both the size of the particle and the position of the particle within the beam cross-sectional area. Laser beams will normally exhibit a Gaussian intensity profile across the beam, such that the intensity is greatest at the centre and falls exponentially away from the centre. Beam radii are frequently expressed as the distance from the centre at which point the intensity has

fallen to 1/e2 (Or approximately 13%) of the intensity at the centre. In order to establish the true size of the particle it is therefore necessary to deconvolve this intensity variation function. This cannot be done on an individual particle basis as it is impossible to know where the particle trajectory lay in relation to the cross-section of the beam. It is not possible, for an individual particle, to know if the scattering was caused by a small particle at the centre of the beam or a larger particle at the edge of the beam. However, if a multitude of particles is measured (and assuming the trajectories of these particles is uniformly spread across the beam cross-section), and if a size distribution is compiled based upon the measured light scattering values for each particle, it is possible to correct this size distribution for the known spatial intensity variation across the beam by conventional deconvolution theory. In order to achieve satisfactory deconvolution of the effects of beam profile on the measured size distribution, it is only necessary to be able to express the beam profile in a mathematical form, and a Gaussian profile lends itself to this readily.

A further example of liquid borne particle detector assembly is shown in Figure 4. In this example, the scattering volume 5 is defined by two parallel closely-spaced windows 6 through which the beam of light from a suitable source such as a diode laser 7 is directed. The beam dimensions are again chosen by the use of suitable beam shaping lenses 8 to ensure that, statistically, not more than one particle is likely the be in the scattering volume, defined as the volume of the beam between the windows, at any instant. The beam dimensions are thus determined with a knowledge of the likely highest concentration of particles which may be present in the liquid. Light scattered by a single particle passing through the scattering volume is incident upon a set of optical detectors 9 arranged symmetrically about the axis of the beam. Again, spherical particles will scatter uniformly to each detector and nonspherical particles will scatter non-uniformly depending upon their shape and orientation to the illumination. The minimum number of detectors to provide the necessary discrimination of spherical particle scattering from non-spherical particle scattering is three. It will also be possible to broadly classify the non-spherical particles based upon the degree of variation in the scatter signals between detectors. This classification may be enhanced by using more than three detectors, and ultimately the discrete detectors could be replaced by a single multi-element detector 10 as shown in Figure 5. The limit to the number of detector elements used is governed principally by the overhead in data processing time which can be tolerated. Again, if the cross-sectional intensity profile of the beam is known, the measured size distribution for

the particle suspension may be corrected for the effects of nonuniform beam profile by the use of deconvolution theory.

Using the detector assemblies as described above, it is possible to differentiate particles within the liquid on the basis of their shapes and sizes, and, by measuring many particles sequentially, to produce a separate size distribution for spherical and other non-spherical particle classes. From these distributions and given a knowledge of the overall dimensions of the pipe carrying the liquid and the flow velocity of the liquid, derivative figures such as the concentration of particles per unit volume of liquid, or the ppm (parts-per-million) by volume of each type of particle may be deduced. It is of note that the velocity of the liquid flow may itself be determined from the length of time a particle is in the laser beam and a knowledge of the beam dimensions. This 'time-of-flight' of a particle through the beam may be found directly from the output signal from any one of the detectors using appropriate time measurement electronic circuitry.

Claims

1. A detector assembly for detecting liquid-borne particles which comprises:

(i) a scattering zone;

(ii) means for illuminating the particle stream within the scattering zone;

(iii) an optical detector adapted to intercept and collect a portion of the light scattered by each particle passing through the illuminating beam;

(iv) data processing means adapted to capture and process the signals from the optical detector for each particle traversing the illuminating beam,

wherein the optical detector has a matrix of optical detector elements, the scattering zone defines a large scattering volume of wide area that is suitably a thin sheet or column and the detector views the wide area of the scattering volume.

2. A detector assembly as claimed in claim 1 wherein the light source is a pulsed light source.

3. A detector assembly as claimed in claim 1 or 2 wherein the light source is a source of ultraviolet light and the optical detector is adapted to detect fluorescent light.

4. A detector assembly as claimed in claim 3 wherein a second optical detector is provided on the opposite side of the scattering zone to said optical detector and one of said optical detector and said second optical detector is arranged to collect the scattered light and the other, the longer wavelength fluorescent light from the particle(s).

5. A detector assembly as claimed in any preceding claim wherein the illumination source is directed along or edge-on to the liquid flow, with the camera viewing the flow face-on.

6. A detector assembly as claimed in claim 1 wherein at the scattering zone the liquid flows sandwiched between transparent sheets or as a 'free column' such as that

delivered vertically downwards from an orifice, not constrained by walls.

7. A detector assembly for detecting liquid-borne particles which comprises:

(i) a scattering zone;

(ii) means for illuminating the particle stream within the scattering zone;

(iii) an optical detector adapted to intercept and collect a portion of the light scattered by each particle passing through the illuminating beam;

(v) data processing means adapted to capture and process the signals from the optical detector for each particle traversing the illuminating beam,

wherein the light source is a source of ultraviolet light and the optical detector is adapted to detect fluorecent light.

8. A method for detecting liquid-borne particles which comprises:

providing a detector assembly as claimed in any preceding claim;

directing a liquid to be tested to flow though the scattering zone;

illuminating the liquid within the scattering zone; and

observing the signals from the optical detector to detect the presence of a particle in the liquid.

9. A method as claimed in claims 2 and 9 wherein the scattering zone is illuminated in pulses, the frequency and duration of the light pulses being arranged such that the volume of liquid in the scattering zone is replaced by 'new' liquid in the period between light pulses, so that all of the liquid passing through the scattering zone undergoes illumination at some time.

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Application No: GB 0203797.6
Claims searched: 1-6, 8, 9

Examiner: Sam Mirison
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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): G1A (ADMP)

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Other: ONLINE: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2278679	(SECRETARY OF STATE FOR DEFENCE)	1, 5, 6, 8
X	GB 2264556	(UNIVERSITY OF HERTFORDSHIRE)	1, 5, 6, 8
X	US 4548500	(WYATT et al.)	1, 3, 4, 6, 8
A	US 4957363	(HITACHI LTD)	
A	US 4977314	(SHIMADZU CORP)	
A	US 4626927	(WYATT TECHNOLOGY CORP.)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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