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A CAMERA AND IMAGE-ANALYSIS SYSTEM FOR *IN SITU* OBSERVATION OF FLOCS IN NATURAL WATERS

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ABSTRACT

An *in situ* suspension camera in combination with an image-analysis system was developed at NIOZ to measure the *in situ* particle size of suspended matter. It differs from other methods in that *in situ* particle size is measured from ~4 μm upwards in a relatively simple and direct way. It can be used in any waters down to ~4000 m depth (with some adjustments to 7000 m) and in water with a suspended matter concentration up to 200 mg·dm^{-3}. In very clear ocean water the system becomes inconvenient because of the large number of photographs that have to be taken to obtain a reliable size distribution. This paper describes the camera and the image-analysis system and gives some results of measurements in the Scheldt river and estuary in April 1989. These measurements show a continuous size distribution by volume between 3.6 μm and 644 μm and a good agreement of the data obtained with the 1:1 and 1:10 cameras.

1. INTRODUCTION

Suspended matter in the ocean and the coastal sea occurs largely as flocs. Their fragility was already noted by NISHIZAWA *et al.* (1954) in the oceanic waters near Japan and more recently also in coastal waters and estuaries by EISMA *et al.* (1983), KRANCK (1984), EISMA (1986) and WELLS & SHANKS (1987). This susceptibility to increased turbulence and the formation of shock waves during sampling contrasts with their stability in the water, even at current velocities of more than 1 m·s^{-1}.

Because of their fragility, the *in situ* size of natural flocs in the water is poorly known. Flocs can be sampled without damage only by divers (TRENT *et al.*, 1978; SHANKS & TRENT, 1979; EISMA *et al.*, 1983) or by submersibles, which provides only a limited number of flocs. Any subsequent analysis, *e.g.* for particle size by Coulter counter or pipet analysis, results in break-up (GIBBS, 1982; GIBBS & KONWAR, 1982). Therefore *in situ* techniques have been developed for observation and size analysis of flocs:

—*in situ* photography (Benthos plankton camera: EDGERTON *et al.*, 1981)

—other camera systems developed by HONJO *et al.* (1984), JOHNSON & WANGERSKY (1985), ASPER (1987) and WELLS & SHANKS (1987);

—laser-Fraunhofer diffraction (BALE *et al.*, 1984; BALE & MORRIS 1987);

—holography (SOKOLOV *et al.*, 1971; CARDER *et al.*, 1982);

—observation from a submersible (SYVITSKI *et al.*, 1983; EISMA, 1986).

The *in situ* camera systems developed so far do not allow analysis of particles smaller than 50 to 200 μm (the Johnson-Wangersky camera and the camera used by ASPER (1987) go as low as 50 μm, the Wells-Shanks camera and the Honjo *et al.* cameras not lower than ~100 and 200 μm, respectively).

This means that a large part is omitted of the size range observed or measured by other means, such as a light microscope, which allows observation down to 3 μm, or Coulter counter, which can measure particles as small as 1 μm. Laser-Fraunhofer diffraction (BALE & MORRIS, 1987), which can measure particles as small as 1.2 μm, involves converting a Fraunhofer diffraction spectrum into a particle size distribution, which gives significant error near the limit of the size range.

Holography needs an object that is immobile with regard to the camera, which can only be approached by very short exposure times and a strong light source. It needs, moreover, an elaborate reconstruction and measuring system.

In an attempt to construct a more direct and simple size measuring apparatus that would include particles down to ~5 μm or smaller, an *in situ* camera system was developed at the Netherlands Institute for Sea Research, Texel, on the basis of photography using a high resolution black-and-white negative film and 1:10 magnification for the smaller size range (below ~100 μm). It was constructed for use down to at least 4000 m water depth. The negatives, showing

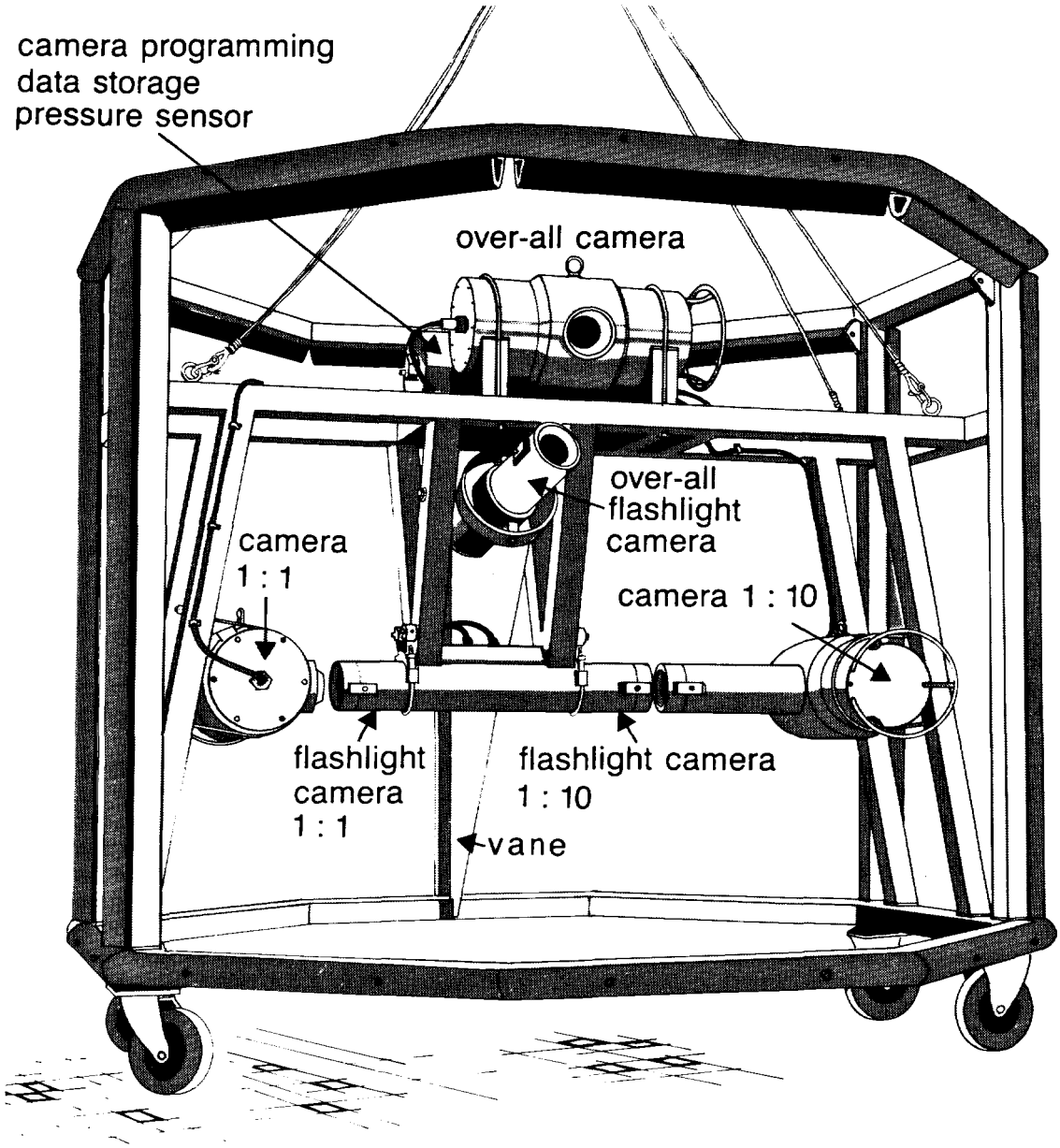


Fig. 1. Sketch of the *in situ* suspended matter camera system, indicating the camera system components.

the suspended particles in white against a black background, are analysed with an automated image analysis system which gives the size and shape of each individual particle (floc) as well as the size distribution of all flocks in a sample. This paper gives a description of the system, together with some results obtained in the Scheldt estuary in fresh and estuarine water.

The *in situ* suspension camera and image-analysis system was developed by a group of scientists and technicians among whom H. Boekel and J. van Heerwaarden were mainly responsible for the design and construction of the frame and the camera system, H. Franken and M. Laan for the electronics and the camera programming, A. Vaars and F. Eijgenraam for the automatization of the image analysis, T. Schuhmacher mainly for the programming of the image analysis and the operation of the camera, and D. Eisma for the basic set-up of the system.

Acknowledgements.—We are much indebted to the NIKON agents in the Netherlands for their cooperation in adapting standard NIKON cameras to the requirements of the camera system, to DIFA Measuring Systems, Breda, the Netherlands for their help with the image-analysis system and the TIM program, and to H. Hobbelink, W. Hart and R. Nichols for the photographs and drawings used in this paper. The development and construction of the camera system and the image analysis were financed by the IAS program of the Ministry of Education and Science, which provides funding for new developments in marine science. To IFREMER (Brest, France) we are much indebted for making the pressure tank facilities available for testing the camera housing. The measurements carried out in the Scheldt river and estuary were made with the LUCTOR of the Delta Institute, Yerseke, and were part of the CEC Project on Transfer Processes and Modelling in the Scheldt estuary (contract no. B16-B-191-NL).

2. THE CAMERA SYSTEM

The camera system consists of an octagonal stainless steel frame, 180 cm high and 200 cm in diameter. It is reinforced by rubber buffer strips, and, for transport on deck, fitted out with 4 small wheels that can be removed when the camera system is lowered into the water. Within this frame 3 cameras are mounted in such a way that there is a minimum of disturbance of the flow of water through the frame and along the camera windows (Fig. 1). A vane keeps the camera windows approximately parallel to the main flow so that the particles are photographed approximately perpendicular to their direction of movement. The 3 cameras are mounted each in a stainless steel tube with the lense protected behind a conical 45-mm-thick window. Two cameras are each directed horizontally towards a flashlight mounted opposite the camera in a stainless steel tube and also provided with perspex windows. Between the window of the camera and the corresponding flashlight is a distance of 32 mm. A third camera is mounted above the two other cameras, also in a stainless steel house, with a flashlight obliquely directed at a $\sim 60°$ angle towards the view-area of this camera.

The third camera photographs an area in front of the camera system frame in the direction of the water flow. It is meant to give an overview of the larger particles, stringers, threads, fragments and organisms that may be present in the water in low numbers and do not pass the apertures between the two other cameras and their corresponding flashligths. The two other cameras photograph the suspended particles that pass through the apertures (Fig. 2). The width of the aperture (32 mm) is sufficient for unhindered passage of the particles, which is based on the experience with the Benthos plankton camera: only at current velocities of ~ 1.2 m·s^{-1} did flocs start to break up because of friction along the windows (EISMA *et al.*, 1983). With the construction of this camera system care was taken to make the windows as smooth as possible and experience up to now has shown that at high velocities (ca 1.5 m·s^{-1}) flocs are not broken: no cloudiness develops such as occurs when the flocs are disrupted. At such velocities, however, the particles go too fast relative to the camera and stripes or bands are produced instead of well-defined particles. This can be prevented by letting the camera system drift with the current. Drifting is generally better because it reduces any increased turbulence and flow-acceleration that may develop in the apertures when the camera system is used in a current.

The cameras used are professional NIKON F3 cameras with a 250-exposure magazine. They were adapted by mounting, in the camera back section, the data-part of a data-back by removing from the motordrive the battery housing and the transmission of the rewind part. This was done to make the cameras as compact as possible so that the inner diameter of the camera housing could be smaller. The lens, in both the over-all camera and the 1:1 camera is a standard NIKKOR 50 mm f/1.4 lens but in the 1:1 camera the lens is mounted with its back towards the camera body with a BR2 ring. Between the ring and the lens another ring of ~ 4 mm has been placed to obtain a 1:1 picture of the particles on the negative. Almost the entire volume of water between the windows of the 1:1 camera and its corresponding flashlight is in focus because the light is almost parallel, and thus virtually all particles in this volume produce a sharp image on the film.

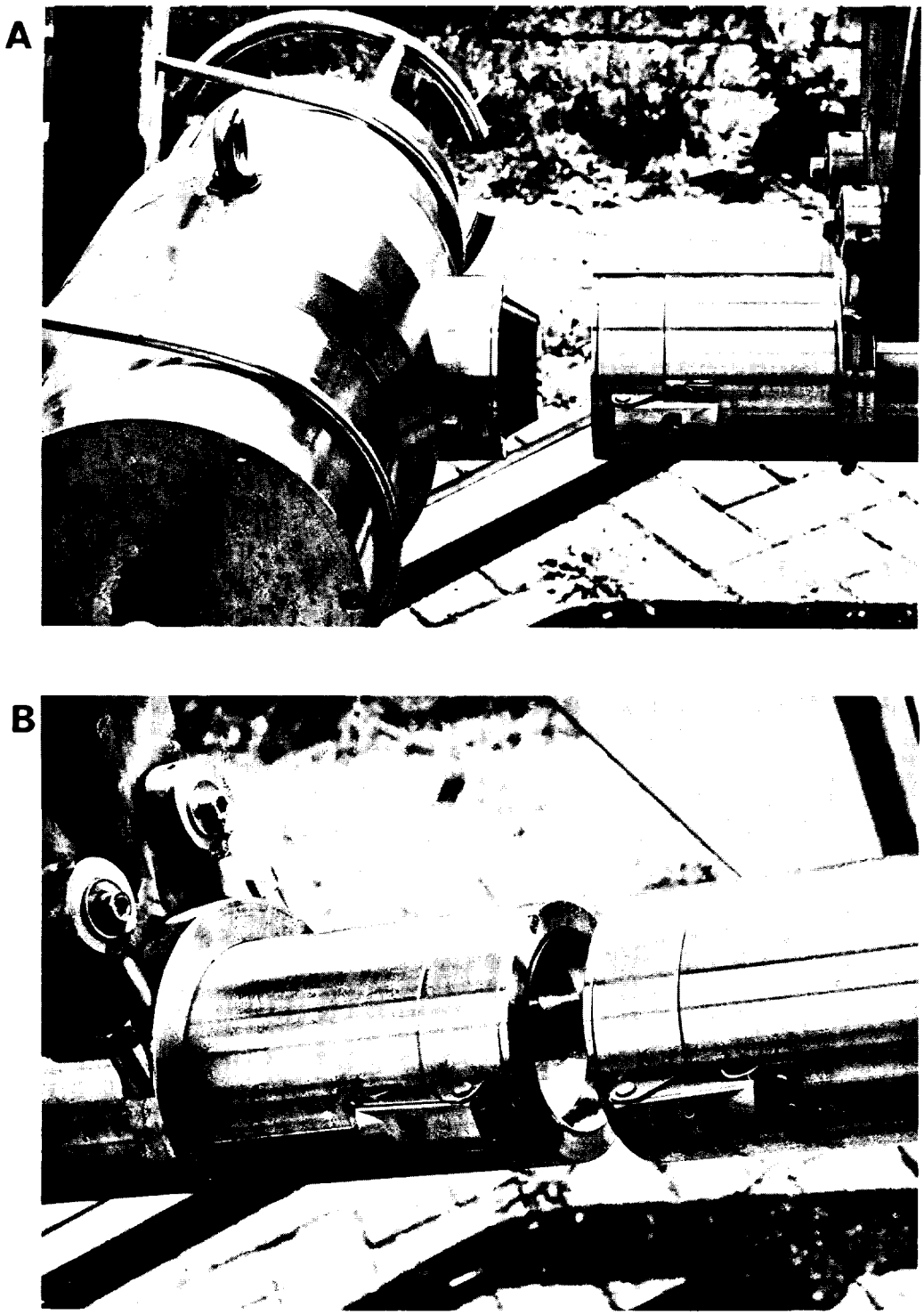


Fig. 2. Detailed view of the apertures between the 1:1 camera (A) and the 1:10 camera (B) and their flashlights.

The 1:10 camera has a standard NIKKOR 35 mm f/1.4 lens, also mounted with its back towards the camera body. The distance between the lens and the film is ~35 mm. This distance was calculated for 1:10 magnificantion and verified on an optical bank (also for the 1:1 camera). It was calibrated with teflon beads of known diameter falling between the apertures in a small water basin. This indicated that the image was indeed 1:10 (or 1:1, respectively) within 1 to 2%. The size of the beads was verified with a microscope and a Coulter counter. In the 1:10 camera the lens is focussed on the centre of the aperture between the windows of the camera and the flashlight. The depth of focus is 0.2 mm, which was verified by moving a 20-μm-thick filament with a micro manipulator between the aperture of the 1:10 camera and the 1:10 flash and making a series of photographs. The negatives thus obtained were sharp within a 0.2 mm distance. Focussing was preferred to parallel light because photographing the small particles over the entire width of the aperture, as done with the 1:1 camera for the larger particles, would produce too many and overlapping particle silhouettes on the film, while narrowing the aperture would result in an increased disturbance of the flow and possible particle break-up. The film used is Kodak Technical Pan-film No. 2415 with a resolution of 3 μm, which allows taking sharp pictures of particles with a minimum diameter of ~3 to 4 μm at 1:10 magnification. This implies that particles with a size of more than ~10 times the film resolution can be observed sharply.

The water volume photographed by the 1:1 camera is 10 cm^3, by the 1:10 camera 0.017 cm^3. In oceanic surface waters, up to 70 flocs >100 μm have been found per dm^3, whereas in the clear ocean water below ~200 m depth, a concentration of ~1 floc per dm^3 or less was found (HONJO *et al.*, 1984). This means that in oceanic surface waters about one floc >100 μm per photograph can be expected for the 1:1 camera and in deeper water about 1 per 70 photographs, but actually more particles will be visible because also particles of 30 to 100 μm are photographed. In the bottom nepheloid layer more particles can be expected. This indicates that in the clear ocean waters of intermediate depths suspended particle size measurements, although possible, are impractical because of the large number of photographs needed for the larger flocs. At high concentrations of suspended matter, or in highly coloured water, a limitation can also be expected because light penetration may not be sufficient and particle silhouettes may overlap. Previous experience with the Benthos plankton camera indicated that this starts to occur at concentrations of 150 to 200 $mg \cdot dm^{-3}$, but it is also related to particle (floc) size: the same mass of suspended material results in higher transparency of the water when the particles are large than when they are small. WELLS & SHANKS (1987) and Wells ß Kim (pers. comm.) have shown that particle (floc) size strongly influences turbidity.

The camera housing has been tested in a pressure tank at IFREMER (Brest) and found reliable down to ~4000 m depth. The housing has now been replaced by an aluminium housing which will allow use of the camera system down to ~7000 m. The total weight of the system is ~800 kg.

3. CAMERA PROGRAMMING AND DATA ACQUISITION

The camera system was designed for use in different environments ranging from the deep ocean to the coastal sea, estuaries, rivers and lakes. Therefore it must also be possible to lower the camera system from small ships capable of hoisting 800 kg but without more sophisticated equipment such as a coaxial cable. Therefore a programming system for the cameras and a data logger were added as well as sensors for pressure and temperature, which make it possible to take photographs at predetermined intervals of time or water depth and to store data. Sensors for other parameters such as salinity, turbidity, and fluorescence can be added. To make the system flexible, programming and data logging were done with a tattletale data logging (model 3) of Onset Computer Corp. This data loggger is built around a 6303 u-processor and the software can be written in a kind of Basic. When the program is developed, it can be put into the memory of the u-processor. For communication and data collection a Toshiba 1200 PC is used with a terminal emulation programme that supports the XMODEM protocol, since the data logger gives a download of the stored data according to this protocol. For the emulation programme MIRROR was chosen, which has a built-in text editor that makes it possible to read data directly when they have been sent to the PC. It is also cheap. Before this, the data have been stored on a floppy disc or hard-disc. Since the data are being sent as an ASCII file, they can also be taken in (*e.g.* in a spread-sheet) for further processing. The data logger is programmed in such a way that the user, through a menu, can introduce his parameters. The last setting is stored in a memory, which remains also after the apparatus has been switched off.

The steering electronics are distributed over 3 prints:
— one for the stabilization of the power and the operation of the power for the flashlights and the cameras
— one for measuring and digitalization of temperature and pressure
— one on which the data logger is placed. The prints are connected by a busprint, on which space is reserved for a fourth print (*e.g.* for turbidity, salinity or fluorescence).

Temperature and pressure are measured with a PT sensor and the data are brought to the data logger through a 12 bit analog/digital converter, while the characteristic is linearized in the data logger. The temperature range that can be measured is from −0.50° to +40.45°C in 4095 steps, *i.e.* with a resolution of 10 mK (0.01°C). Before lowering, the calibration value and a 0-correction have to be introduced into the data logger. Pressure is also divided into 4095 steps: with a 600 Bar pressure cell a range of 0 to 600 m waterdepth can be measured with a resolution of 15 cm. Because the system has to be used in the deep ocean as well as in shallow water, it must be possible to change the pressure cell without difficulty. Therefore it is located outside the electronics housing. When changing the pressure cell only, the full-scale value and the calibration value of the new cell have to be introduced into the data logger so that all pressure measurements are converted according to the new scale. The 0-correction for the pressure cell is done automatically on deck before each lowering. The housing of the batteries and the electronics is made of Constructional Aluminium tube.

The actual operation is as follows, as indicated in the scheme of Fig. 3. The photographs can be taken on the basis of pressure or time intervals and are made during the lowering because during going up the water is too much disturbed by the rising camera frame to take reliable pictures. The exposures are grouped in blocks and the number of exposures in a block is determined beforehand. All blocks in one cast have the same number of exposures. When a predetermined interval of time or pressure has passed, a block of exposures is made while the camera remains in place. A maximum of 99 blocks can be programmed with each block consisting of a maximum of 99 exposures. In practice, however, the total number of exposures in each series is limited to only 250, because the camera motor drive mechanism is constructed for this maximum number of exposures. Between the blocks a blank exposure can be made by activating the camera without activating the flashlight. Before and after each block, temperature and pressure are measured and the data are stored, together with the block number, the number of seconds used for the exposures in the block, the remaining capacity of the batteries and an indication

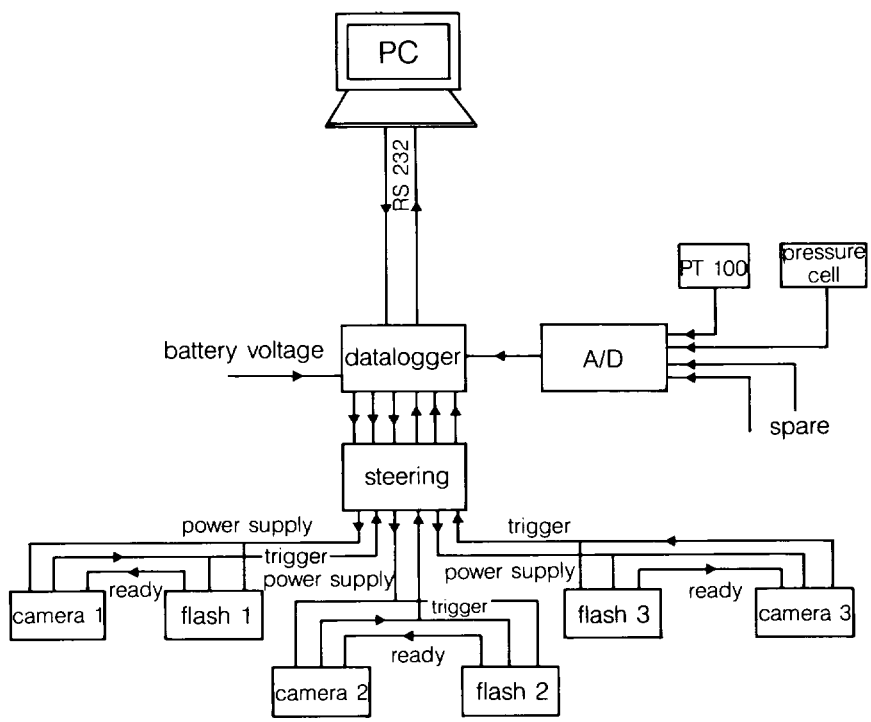


Fig. 3. Operation scheme of the camera system.

whether the camera has been exposed. Also a temperature-depth profile is stored. During one downcast ~3500 measurements can be made.

A block of exposures starts when the data logger switches on the power for the cameras and the flashlights. When the flashlight is charged (which needs, depending on battery charge and flashlight type, ~3 to 11 sec) and is ready to flash, it gives a 'ready' signal to the camera, which opens the camera shutter and gives a trigger pulse to the flashlight, that discharges. The same pulse also goes to the data logger, which disconnects the power and puts the exposure counter one point further, and transports the film in the camera. The 3 cameras are usually triggered at different intervals: the 1:10 camera more frequently than the 1:1 camera because the volume photographed is much smaller, and the over-all camera only a few times. Each time the logger waits until all cameras are ready again. Then the cycle is repeated until all exposures in one block have been made. The maximum time interval between exposures is 20 sec. If this time is exceeded, *e.g.* because the flashlight is not ready in time, the status bit for the camera is 1; if a block is completed successfully, the status is 0.

The power for the entire system comes from 12 nickel cadmium batteries of 7 A/h. They can easily provide the current for the 3 flashlights (simultaneously) and can be used for many hours without recharging. Complete recharging takes 14 h. For this a loading block has been made which is also used for operating the flashlights and transporting the film in the cameras on deck. When the system is being programmed, the remaining capacity and the battery voltage are indicated, which shows when the batteries need reloading.

The flashlight for the 1:10 camera operates at a speed of 2 to 3 microsec, 1500 V and 1.8 μF and gives off 2 Joules; for the 1:1 camera flashlight the speed is 20-30 μsec at 600 V and 800 μF while ~38 Joules is given, which allows for a minimum loss of sharpness caused by the movement of the particles relative to the camera. At an average current velocity of 1 $m \cdot s^{-1}$ and the suspended particles moving at approximately the same speed (which occurs regularly in tidal areas), the displacement of the particles relative to the camera during the flash is 2 to 3 μm for the 1:10 camera and 20 to 30 μm for the 1:1 camera. The blur caused by this, is partly corrected by the image analysis, but for particles <10 μm photographed by the 1:10 camera and for particles <100 μm photographed by the 1:1 camera, particle size measurements made at such current speeds are significantly influenced by the particle movement relative to the camera. As indicated above, this can be corrected by letting the camera system drift with the current during measurements.

4. IMAGE ANALYSIS

The camera system produces large numbers of photographs (negatives) that have to be analysed for size and shape of the particles pictured on them. Using the negatives has the advantage of avoiding printing. An additional advantage is that the unavoidable dust particles turn up black during optical scanning, whereas the particle silhouettes on the negatives are white. Because of the numbers of negatives and particles involved, the number of particles per unit area (representing unit volume of water) and their surface area are determined with an automated image analysis system.

The negatives, produced from the film by standard developing techniques, are mounted on an x-y steering table and each negative is scanned under a microscope. The size of the scanned image is usually smaller than the negative so that more than one scan of the same negative can be made. After an image is scanned, a pulse is given from the analysis system to the steering table mechanism and the negative is transported automatically. Then the same procedure is repeated with the next image.

The image as obtained through the microscope is recorded with a CCD camera which gives an analogue video signal to a PC vision frame grabber. The framegrabber digitizes the image to pixel values in a window of 521 x 521 pixels. Complete white gets a value of 255, complete black a value of 0 and in between are 255 grey values. The digitized image is sent to an image monitor and mathematical operations are carried out with a compaq 386 computer. The software package used for this image handling was developed at Delft Technical University and improved and commercialized by DIFA Measuring Systems, Breda, the Netherlands. It is called TIM and makes it possible to improve the image by equalizing the background light intensity and filtering out noise. When the background light intensity is found to vary, it is filtered by determining a weighted average over a limited area, adding a large number of pixels, dividing by the total number of pixels and substracting this bare level from the measured background. The noise is filtered out of the image by substracting and adding pixels to the edges of the particle images. This involves first taking away a desired number of pixels from a particle image edge, and then adding the same number of pixels. If a particle is large enough, nothing has changed after this procedure, but a small particle that has disappeared will not reappear again. In this way small groups of pixels or single pixels that can be regarded as noise are removed.

Sharp-edged particles that were in focus when the exposures were made can be separated from the particles that were out of focus by introducing a threshold level. Above this level a pixel becomes

white, below this level it becomes black. In that way particles that are not sharp and have a low grey value will not be counted and analysed. Once a threshold level is chosen, all the negatives have to be treated with this same level to make the results comparable.

On the black-white image, which is the result of applying the threshold value, the number of pixels within each particle can be counted easily, so that the size and area of each particle can be calculated, as well as their concentration. On the basis of these data a size distribution can be constructed combining the data from the 1:1 and 1:10 cameras taken during the same time period (which is in the order of several minutes). Since the 1:1 and 1:10 cameras are situated at some distance from each other, not the same particle population is photographed. When combined, the results of the two cameras are therefore assumed to give a homogeneous particle population within ~1.5 m distance as well as during the period of exposure.

Noise and threshold level may vary for different sets of exposures. To obtain comparable data from one set, a set of values has to be introduced beforehand into the computer program steering the automatization. These include the threshold level, numbers of pixels to be substracted and added to remove background noise, the scanning grid, the number of images to be scanned per negative, the scale of the negative, the real size of one pixel (which is related to the magnification by the microscope and is calibrated by putting a scale under the microscope), the water volume represented by the image, and a division into particle size classes. Experience shows that the negatives of one film of 250 exposures, as well as of other films exposed and developed under the same conditions, can be treated in the same way, *i.e.* with the same set of pre-set values. Differences in apparent size in different sets of negatives can arise when different values for threshold levels and noise filtering have to be used. The best way to calibrate this is to compare by eye the treated image with the untreated one, which shows the real size of the particles. Since in both images the particles are at the same place on the screen, individual (large) particles that are sharp in the untreated image can easily be compared with the same particles in the treated image by switching quickly from one image to the other and the system can be adjusted until the sizes are the same.

There is no upper limit to the size of the particles that can be detected, although particles larger than a few cm will become a problem because they will show up larger than the negative, also in the 1:1 camera. A correction for this provides the over-all camera, which will show these large particles and give an indication of their number per unit volume of water. The lower size limit, as stated above, is in the order of 3 to 5 μm, although particles as small as 1 μm can be detected. Particles smaller than 3 μm may not be photographed or badly defined, because of inhomogeneities in the emulsion. This may also occur with some larger particles so that for quantitative analysis 5 μm is a safe lower limit.

5. *IN SITU* SIZE DISTRIBUTION OF THE SCHELDT RIVER AND ESTUARY

As an example of the results that are obtained with the *in situ* camera system, size distributions are shown that were obtained in the Scheldt river and estuary in April 1989. Photographs were made between Vlissingen and Temse in surface water, in near-bottom water at ~1 m above the bottom and at intermediate depths (Fig. 4). In Fig. 5 some 1:1 and 1:10 negatives are reproduced. In Fig. 6, for a few selected measurements ranging from fresh water (Temse) to saline water (PvS - SS), the particle volume in a range of size fractions is given (both scales are logarithmic). The volume of each measured particle was calculated from the particle diameter assuming the particles to be spheres. The particle diameter was calculated from the particle area in the photographs, measured by the total number of pixels, taking the area as πr^2 and 2r as the diameter. The total volume of the particles in a size fraction is the sum of all particle volumes in that fraction.

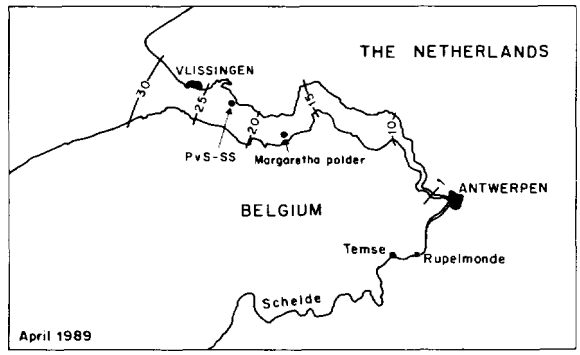
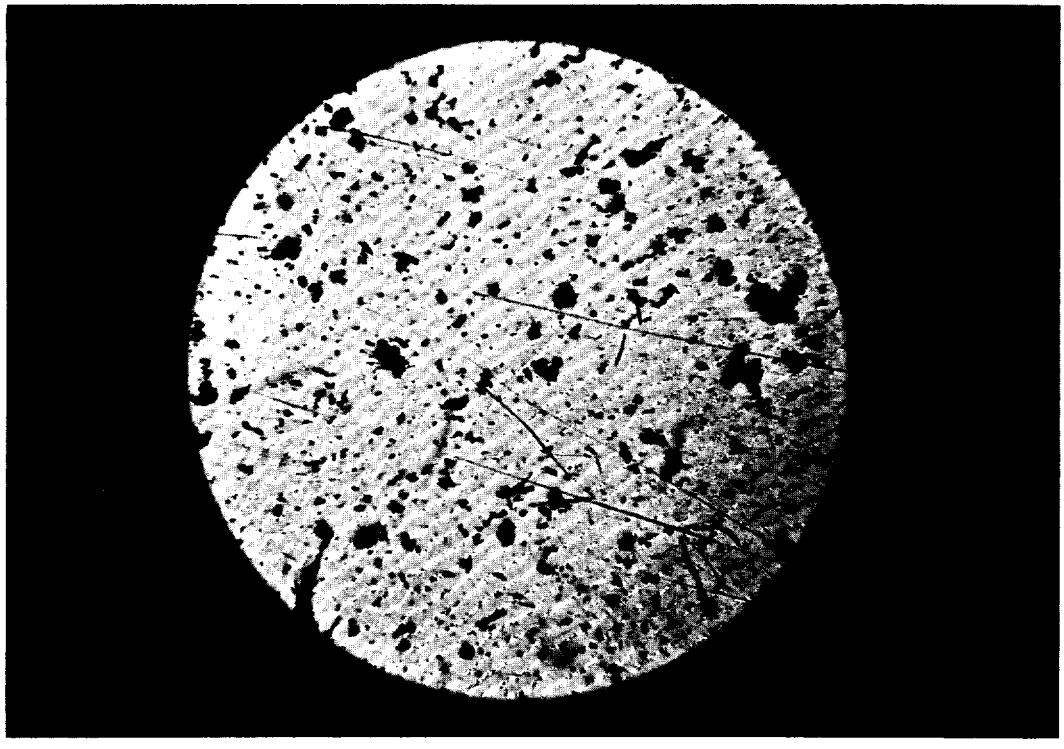


Fig. 4. Sampling points in the Scheldt river and estuary in April 1989. Numbers indicate salinity (in S-units).

There is a good overlap between the results of the 2 cameras for each measurement, with deviations at the lower and upper ends of the size range. At the lower end this is caused by the resolution of the film which is near 3 μm, as was discussed above. At the upper end it is caused by the small number of particles that is measured in the largest size fractions. This makes the results for these size fraction statistically unreliable. The curves are based on at least 300 particles measured per camera, so that the total curve is based on at least 600 particle measure-

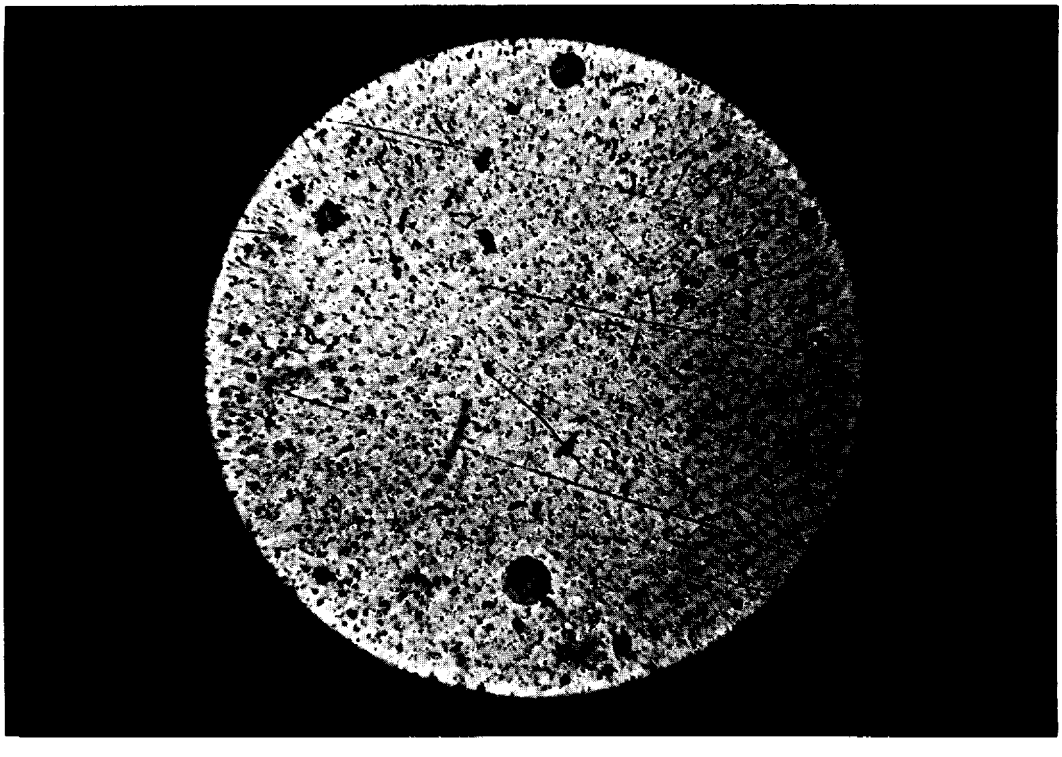
A1



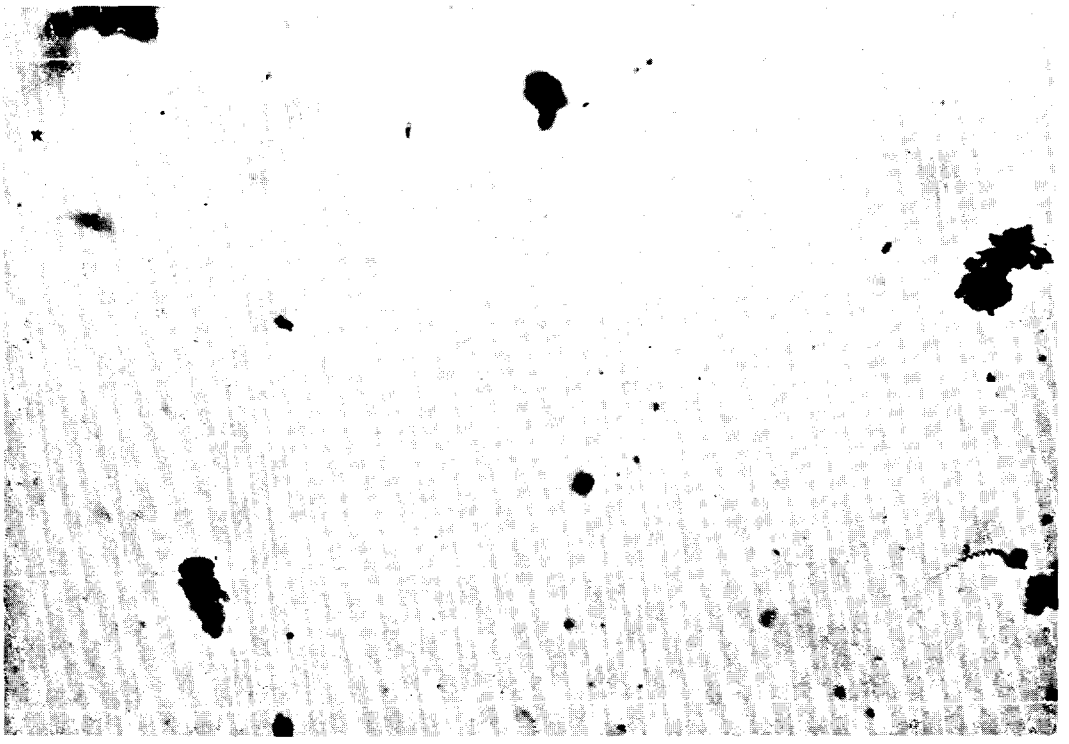
0 5 mm

Fig. 5. Examples of negatives (24 x 36 cm) produced by the 1:1 camera (A) and the 1:10 camera (B, overleaf) in the Scheldt river and estuary. A1, B1 freshwater; A2, B2 *ca.* 22.1‰ S.

A2



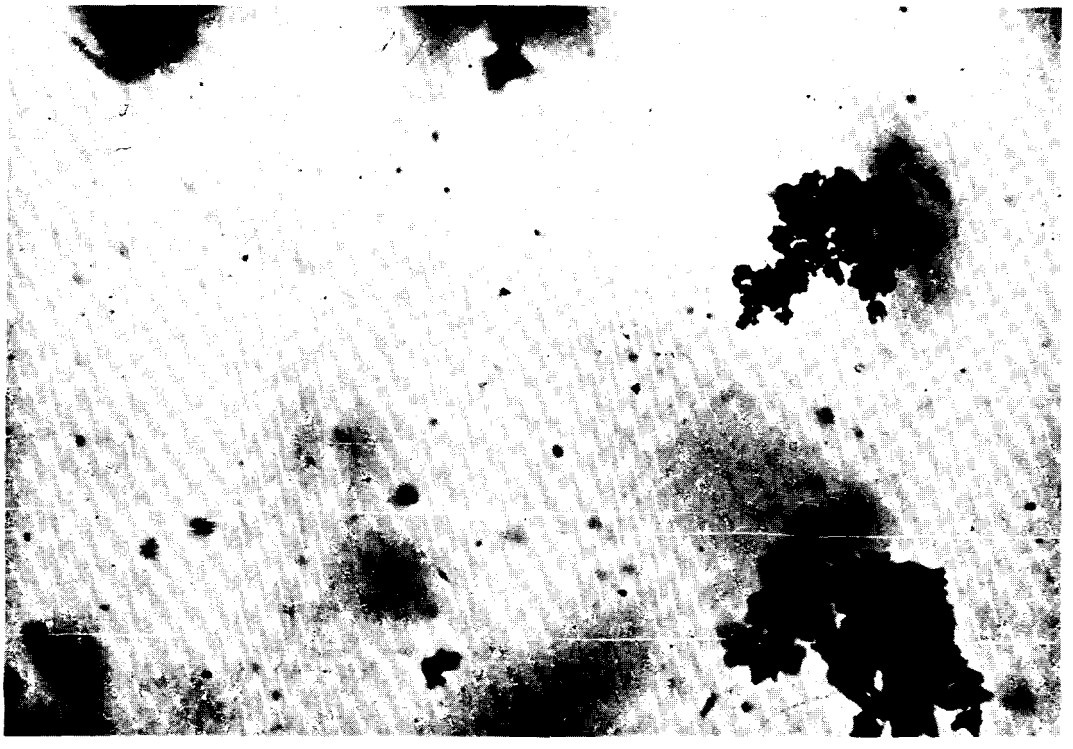
B1



0 5 μm

Fig. 5. Examples of negatives (24 x 36 cm) produced by the 1:1 camera (A, overleaf) and the 1:10 camera (B) in the Scheldt river and estuary. A1, B1 freshwater; A2, B2 *ca.* 22.1‰ S.

B2



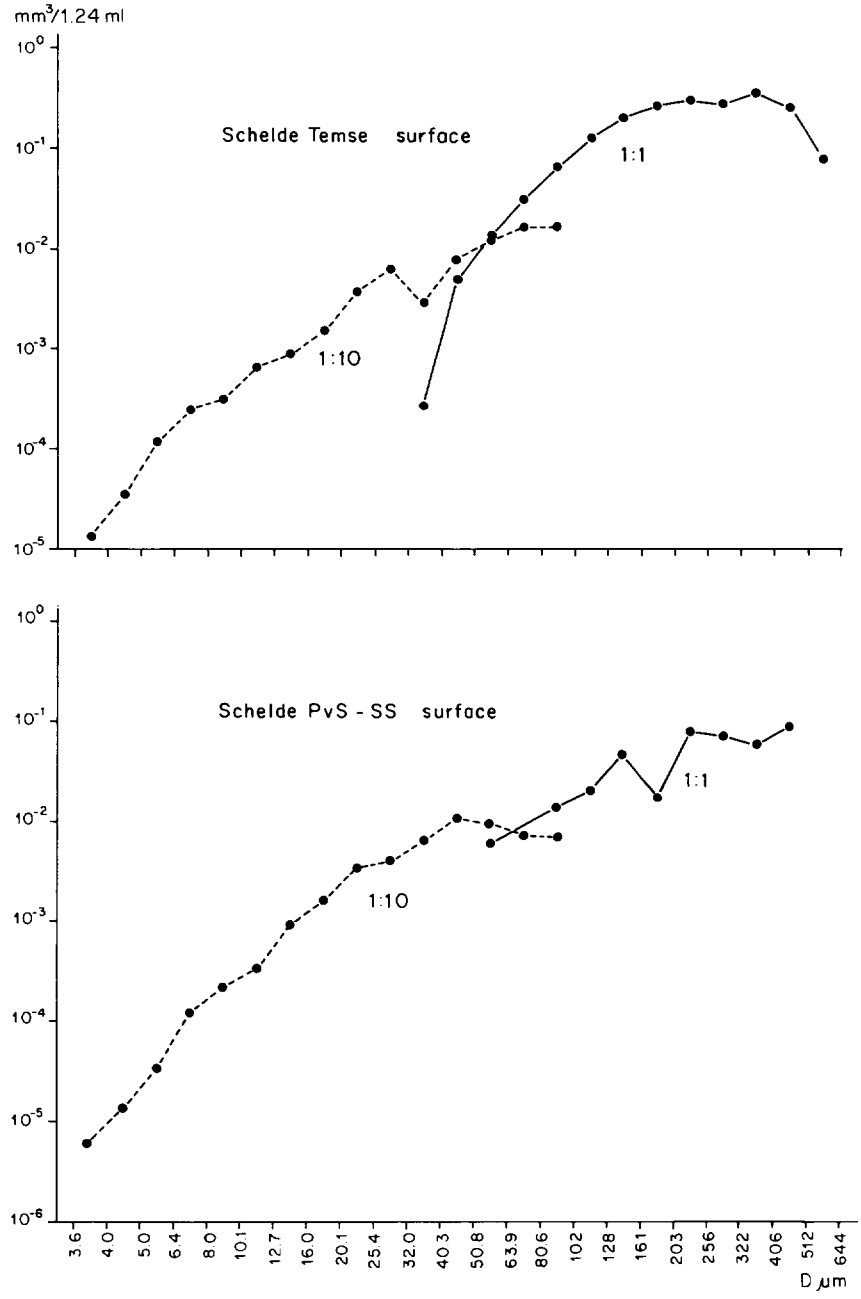


Fig. 6. *In situ* particle size distributions by volume measured in the Scheldt river and estuary at the stations indicated in Fig. 4.

ments. This minimum number is based on the particle counting statistics developed by VAN DER PLAS & TOBI (1965).

In Figs 7 and 8 the data are represented in a different way. The distribution of particle number per unit volume (number on a linear scale, particle size on a logarithmic scale; Fig. 7) shows better the larger number of coarse particles in Temse surface water as compared to Scheldt PvS - SS surface water. Since the particle volume increases with the third power of the particle diameter, an important part (by volume) of the suspended matter is present in the coarse size fractions. This is shown in Fig. 8: at both stations more than 80% of the particle volume is in the size

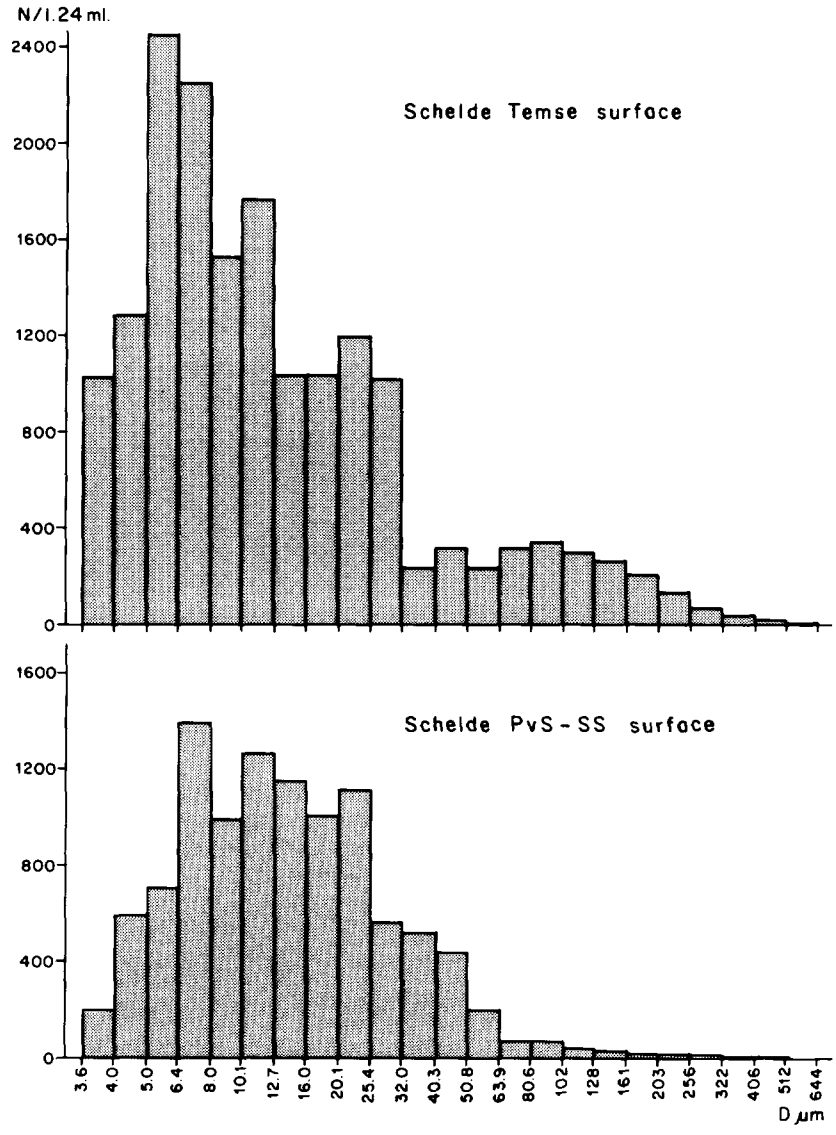


Fig. 7. The *in situ* particle size distributions given in Fig. 6, represented as number of particles (N) per unit volume in a range of size fractions.

fractions >102 µm. As Temse surface water is fresh and the salinity of PvS - SS surface water is 22.1, the presence of more coarse particles (flocs) in the Temse surface water is an indication that saltflocculation is not important. This might suggest the reverse — deflocculation — but the data obtained at other stations indicate that also coarser size distributions occur in the saline part of the estuary: a more elaborate treatment of the size distribution data obtained during this cruise is being prepared.

The Scheldt data indicate that with the *in situ* camera system reliable particle size distributions can be obtained from ~4 µm upwards. An example of the third camera, which gives an overview of large particles that may not pass the apertures between the cameras and their flash, cannot be given because in the Scheldt river and estuary such particles — very large flocs, filaments, stringers, *etc.* — were not present during the measurements. Plankton organisms, present in considerable numbers in the Scheldt river and estuary in April 1989, did not give problems as they show up on the negatives as grey transparent shapes that are filtered out during the image analysis.

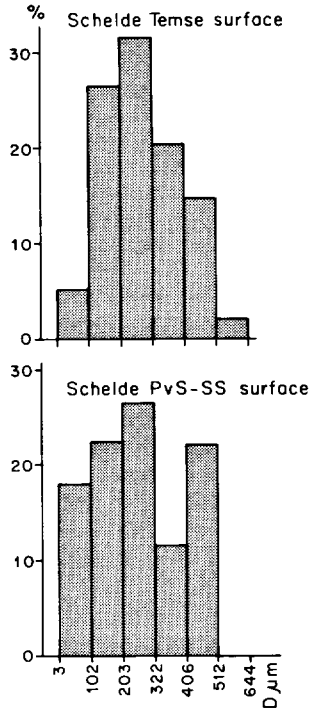


Fig. 8 Percentage of the total volume of suspended matter present in the different size fractions of the *in situ* particle size distribution given in Fig. 6.

6. CONCLUSIONS

The suspended matter camera system developed at NIOZ to measure *in situ* a wide range of particle sizes in a relatively simple and direct way gives reliable *in situ* size distributions from ~4 µm upwards. The method consists of photographing the particles directly in the water with a 1:1 and a 1:10 camera and analysing the negatives for particle size. At velocities of up to 1·5 $m \cdot s^{-1}$ no flocs were seen to break up because of shear caused by the instrument, but at velocities of ~1 $m \cdot s^{-1}$ and higher the exposure times were too long to obtain a sharp image. At such velocities it is necessary to let the instrument drift with the current so that the velocity of the suspended particles relative to the cameras is reduced. The camera system can be used safely down to ~4000 m (with some alterations in the near future, to ~7000 m). At suspended matter concentrations of ~200 $mg \cdot dm^{-3}$ and higher the instrument may become useless because of particle overlap and limited light penetration, but this also depends on size of the suspended particles because with coarser particles the suspended material is contained in fewer particles. At very low suspended matter concentrations, like in clear ocean water, the measurements become unpractical because of the large number of negatives needed to obtain a reliable size distribution. As a rule, a minimum number of 300 particles is to be measured by each camera for each measurement.

The camera system is fully programmed before being lowered into the water and works on batteries so that a coaxial cable is not needed. Pressure (water depth) and temperature are measured simultaneously when the camera is being operated; salinity, turbidity, fluorescence *etc.* can be added. Per lowering ~3500 measurements can be made. The number of photographs that can be made is limited by the capacity of the film-holders of the motordrive mechanism, which for each camera is 250. The cameras are working on flashlight. Because the volume of water photographed with the 1:10 camera is about 1% of the volume photographed with the 1:1 camera, more 1:10 negatives are needed to obtain a reliable measurement. Although the finer fractions contain much more particles, in practice the number of measurements that can be made during one downcast is limited by the capacity of the 1:10 camera.

The image analysis system also works automatically after the values for the basic parameters have been set, primarily the background correction, the threshold level, and the microscope magnification. When the negatives have not been exposed and/or developed under the same conditions, different sets of values are needed and the system has to be calibrated. This can be done by comparing the treated image with the untreated one and adjusting the system until the particles in both images have the same size. The entire system — cameras and image analysis — is easy to handle and can be applied in any area and from any vessel that can hoist 800 kg. A drawback is the necessity of using 2 cameras, which need to have a good overlap. Although in practice this does not seem to be a serious problem, measurement of the entire size range at one time is to be preferred. Only opaque particles are measured which give a white area on the negative. Grey or black particles (including plankton and dust on the negative) are not measured.

Another drawback may be its size and weight, which are large for a small ship. In spite of its stability on deck of a moving ship, a lighter and smaller instrument would be more convenient in calm water. Weight reduction is possible by using lighter materials but the size cannot be reduced very much because the cameras and flashlights have a minimum length and there is a minimum width for the apertures between the camera and the flashlight windows to avoid floc-breakage. For the same reason water must be able to pass as freely as possible through the frame.

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