Experimental measurements of the scattered-light polarization from different liquid flows

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An experimental system designed to measure very low optical powers, of the order of a few picowatts, is presented. Its main aid is to detect the polarisation state of scattered light from a fluid flow, in different angular directions with respect to the longitudinal axis of the flow. A laser beam incident linearly polarized crosses the fluid flow orthogonally. The scattered light is detected by means of a photodetector situated behind a lineal polarizer whose orientation can be rotated. The outgoing electrical signal is amplified by means of a Mode-lockin amplifier and is digitally processed.

1. INTRODUCTION

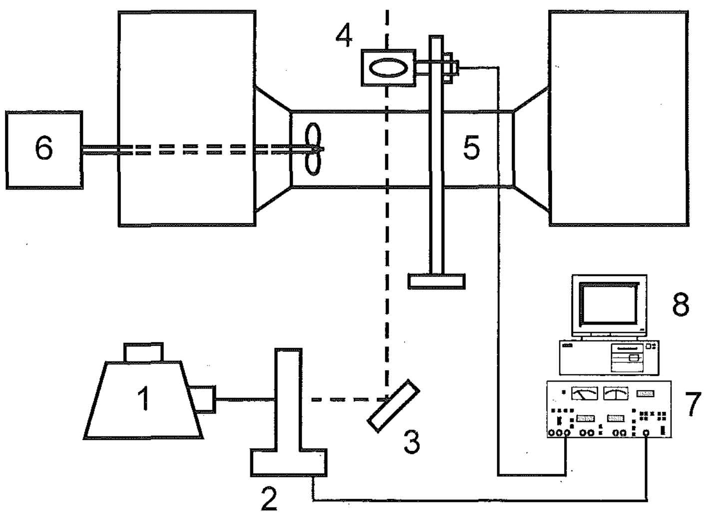
Among the most used methods of Flow Visualisation and Optical Testing those involving changes in amplitude, direction, frequency or transmitted or scattered light phase by the fluid are found. However, the changes in polarisation, that have often been used to measure the concentration of foreign materials in water, have not been applied to the design of the experimental systems in the same way as previous ones.

One particular case, studied by some authors, is the optical effect of streaming birefringence, which states that in certain liquids or liquid solutions change to birefringents by the action of shear forces in a flow, which forces these particles or large molecules to align themselves in a preferential direction. The fluid is then anisotropic or birefringent. Such is the case in Boyer *et al* (1), McAfee and Pih (2) and Horseman and Mertzkerch (3), among others. The oldest and most widely used technique for visualising the flow of birefringent liquid is the apparatus called a polariscope.

The principle objective of this paper consists of describing an experimental system which permits, like a polariscope, the detection of the changes in polarisation of scattered-light through a fluid flow, but in this case by means of direct measurements of the low optical potencies corresponding to the different directions with respect to the longitudinal axis of the flow. The results obtained up till now from the experiments consist in the determination of small concentrations of foreign materials in the water and the obtaining of polar diagrams of the polarisation state corresponding to the different concentrations and directions of observation.

2. EXPERIMENTAL SET-UP

The experimental system is structured as shown in Fig. 1. The linearly polarized Argon laser beam which emits at wavelengths of 488.0 nm and 514.5 nm with a power of 12 mW per line, falls orthogonally upon the circular pipe. This is a cylinder made of Perspex, 80cm long and 20cm in interior diameter. The fluid contained can be still or flowing as the result of a pump which permits the creation of flows whose Reynolds number may have values of more than 2,000. A stirring system permits by means of an electric motor the stirring of the fluid with different types of propellers.



1.- Ar Laser	5.- Circular pipe
2.- Chopper	6.- Stirring system
3.- Mirror	7.- Lockin Amplifier
4.- Detection system	8.- PC

Fig. 1.- Experimental system.

A detection system may be situated in different positions with respect to the principle directions of flow and the incident laser beam, orthogonal between them. This is made up of a photodetector which captures the light by means of a small, 3mm interior diameter carbon-fibre tube. Between this tube and the photodetector a lineal polarizer has been inserted. This polarizer whose degree of polarization, measured directly with the laser beam corresponds to $\lambda = 488.0$ nm is $P = 1/3$. The polarizer-photodetector unit is mounted on a support that allows its complete rotation, regulated by an electric motor. Thus, the detection system has two degrees of freedom: its position with respect to the axis of the circular tube and its angular position with respect to the axis defined by the direction of incident light on the polarizer-photodetector.

The measuring system consists of a Mode-lockin amplifier which, by means of a GPIB card is connected to a computer which can transfer the control of the amplifier through software especially developed for this purpose. The lockin works in an intensity mode in the application and the reference frequency in the acquisition of data is provided by a chopper interposed between the outgoing laser and the circular pipe. The reference frequency is selected at around 2350 Hz, avoiding that it be a multiple of 5 in order to obtain a filtering suitable for the possible effects of environmental optics.

The zone surrounding the detection system is suitably darkened in order to avoid the filtration of reflections that could alter the purity of the measurements. Under these conditions the system is capable of acquiring data from the photodetector of the order of 1 pA, with error levels of the order of 10% , with values much less when the intensity increases. Given that the photodetector response is of 0.36 A/W in the wavelength used, the system allows optical powers of the order of a few picowatts to be collected, which represents the irradiance in the circular surface of 3mm in diameter which serves as the intake of the photodetector.

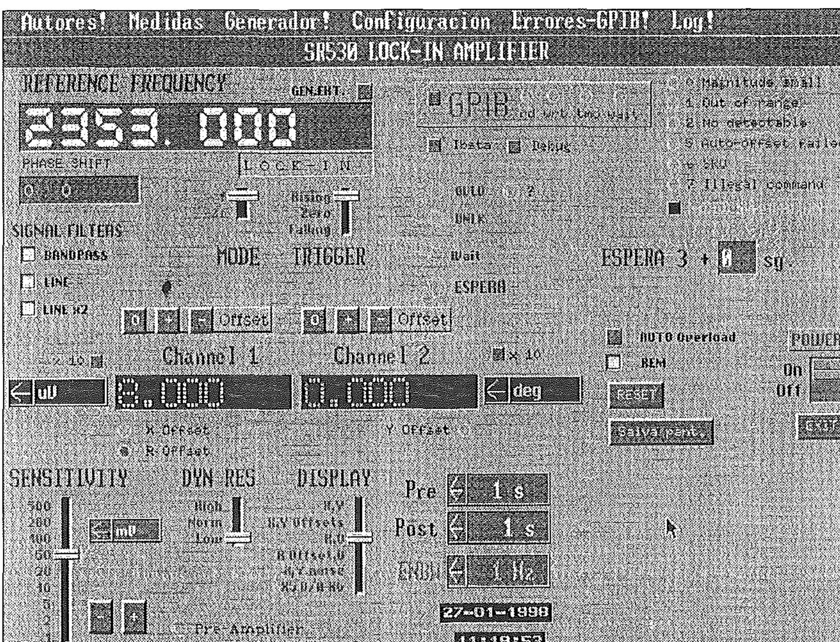


Fig. 2.- Lockin Amplifier PC control.

Figure 2 shows the PC screen from where lockin amplifier and data acquisition system are controlled. A specific software programme, specially designed for this occasion, runs the system.

3. THE MEASUREMENT OF CONCENTRATIONS OF FOREIGN MATERIALS IN WATER AND POLARISATION CHANGES BY SCATTERING

As a first test to verify the correct functioning of the system, the change in intensity corresponding to scattered-light in different directions according to the concentration of different foreign materials in still water, milk and sugar in particular, was measured. Given that the total capacity of the deposits and the circular tube is of the order of 300 litres, it can be experimented with an ample margin of concentrations.

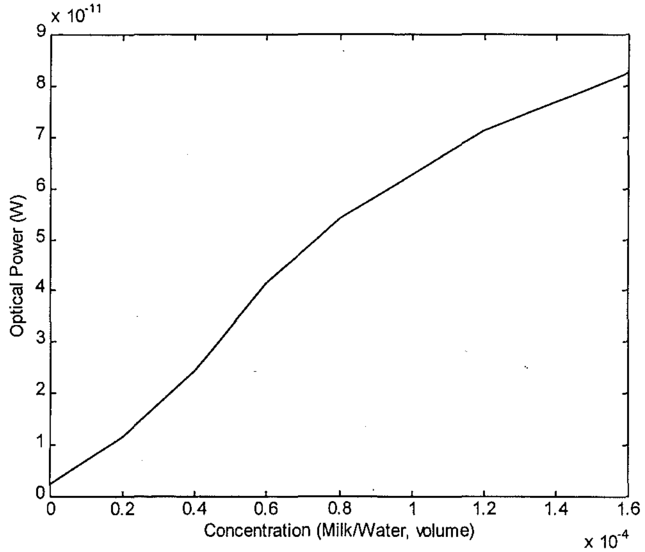


Fig. 3.- Optical power received as a function of the milk concentration.

Proceeding in the second phase to obtain measurements of the scattered-light polarization state, in still water, for different concentrations of milk or sugar and varying the position of the detection system. For each direction the polarizer is rotated through a complete turn. In Fig.4 the polarization diagram corresponding to polarizer response to the outgoing laser beam at 10 mW is shown. The line corresponding to $\lambda = 488.0$ nm has been used.

In Fig.5, a polarization diagram corresponding to an inclination of the detection system of 45° with respect to the direction of the incident laser beam and for a concentration of 10 ml of sugar in 300 l of water (right) is shown. The differences between both diagrams is clear. The following measuring phase is directed to detecting the global properties of different types of flow by means of the analysis of the polarization diagrams experimentally obtained. Measurements corresponding to Reynolds numbers understood between 3,000 and 20,000 and flows behind spherical obstacles of different diameters, likewise, in flows produced by propellers, have been taken.

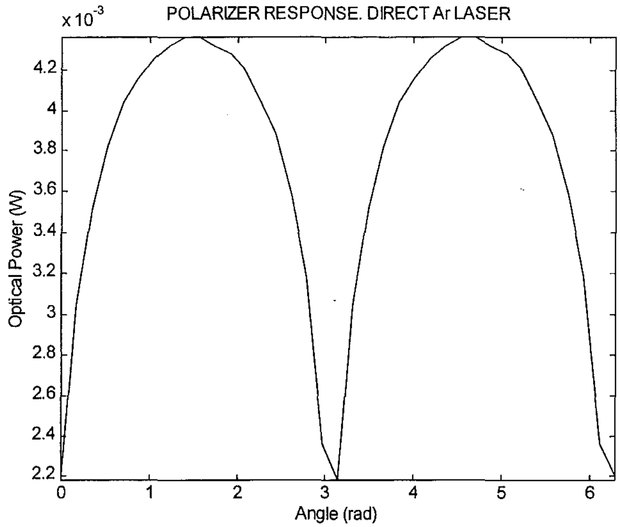


Fig. 4.- Polarizer response.

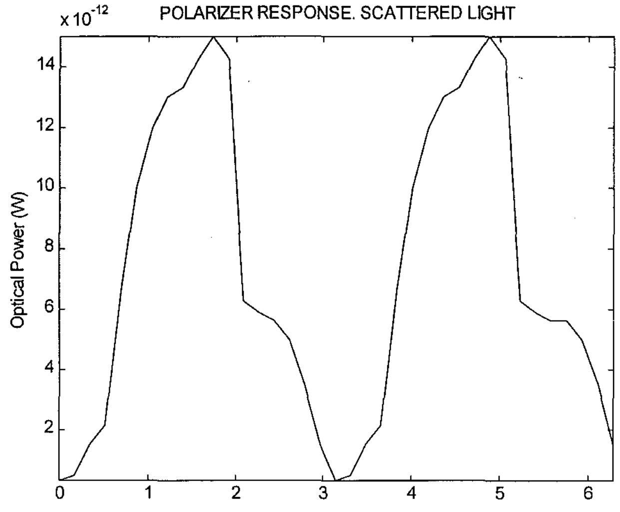


Fig. 5.- Polarizer response to scattered-light.

5 CONCLUSIONS

An experimental system of relatively low cost has been developed, which allows the taking of quite precise measurements of scattered-light in which small concentrations of molecules or dispersed particles have been introduced. The system has proved effective in the measurement of polarisation changes by scattering in conditions of still water and it seems possible to expect results soon in the study of general properties of fluid flows in pipes.

REFERENCES

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(2) **McAfee, W.J., and Pih, H.** "Scattered-light flow-optic relations adaptable to three-dimensional flow birefringence". Exp. Mech. 14, 385-391. 1974.

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