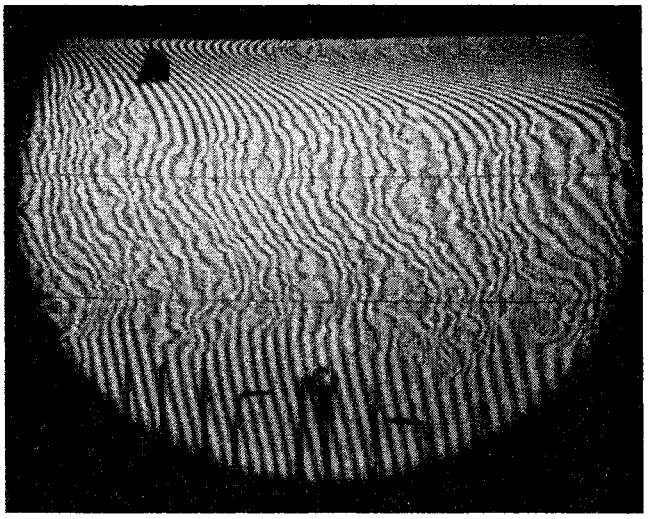

Fig. 2 Holographic interferogram of submarine wake in stratified flow.

that the two miscible fluids—pure water above and salt water below the submarine—are not well mixed. This observation may well be caused by a return of the fluid mixed by the propeller to the initial density stratification. If the mean density profiles are axisymmetric, the data could be reduced by a modification of the Abel inversion integral. Data reduction of this type has not been attempted. Localized turbulent statistics can be measured by cross viewing the data from a single hologram. This concept has been applied to the data reduction of the projectile wakes elsewhere.[5]

The tank was filled about 30 min prior to running the experiment. This time is probably enough time to set up thermal equilibrium of the air-water and wall-water interfaces surrounding the fluid. However, 10 min before recording the data, the tank, which was mounted on rails, was rolled into the test section of the holocamera. This movement probably disturbed the thermal layers surrrounding the fluid. Since the interferogram is recorded as a time sequence of two holograms, it is suspected that the large fringe shift (5 fringes) within the first centimeter of the surface is caused by surface layer cooling by evaporation during the time interval, which was about 1 min. Reduction of the fringe data at the interface shows that this fringe shift corresponds to temperature drop of a maximum of 0.1°C. Because thermal layers in equilibrium are known to have a temperature difference of several tenths of degrees, this surface layer phenomena could be explained this way.[6,7] The irregularities in fringe pattern at the interface may be caused by submarine disturbances or by convective recirculation or both.

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Pollution Monitoring: An Engineering Challenge

J. M. Snodgrass*

Scripps Institution of Oceanography, La Jolla, Calif.

WITHOUT question, pollution has emerged as one of the key "buzz words" of the early 1970's. Pollution has long occupied the realm of the biologists and is no stranger to the political arena. By now it has become quite clear that, if we are to make headway against undesirable pollution, we must begin with facts and facts in turn are validated by measurement and numbers.

We have made an exceedingly abrupt beginning and have come already face to face with our problem which is, how do we go about making the necessary measurements and obtaining essential numbers? It is not our purpose to debate the question of whether we need monitoring systems for pollution measurements or not but rather to address specifically the question of how we may go about the measurements of marine pollution. Today most pollution measurements are made by utilizing manned "monitoring" stations. By implication, manned stations implies that man hours are required. In fact, very large numbers of man hours may be required for collecting samples and carrying out the subsequent analytical analysis. With present techniques, the labor costs tend to be the dominant parameters for large-scale monitoring systems.

From the engineering standpoint, there is a very great challenge in that sensors for monitoring pollutants for the most part simply do not exist and there is no such thing as "off-the-shelf" availability. At the very least, major development of sensors is badly needed and in most cases the sensors have not yet been invented.

Perhaps it is well to elaborate at this point as to the implication of the term sensor. It is quite true that measurements are now being made of pollutants in the marine environment but this is often done by collecting extensive samples and carrying out a variety of chemical manipulations in which the actual measurements may be made by means of various chromatographic techniques. The chromatograph as the end element in the analytical technique employed may be considered to be a sensor, but this is not the kind of sensor which we are considering. We are considering a sensor to be a relatively simple package device that is capable of responding to the desired measurand and supplying as an output an electrical signal proportional to the concentration or magnitude of the measurand. A temperature sensor such as a thermocouple or a thermistor would be considered to be ideal simple sensors and a pressure sensor such as a vibrotron would also satisfy our requirement. Further, a suitable sensor should be capable of operating in an unmanned, unattended system for protracted periods of time. Specifically, we are concerned with the feasibility of developing sensors in lieu of complicated analytical techniques.

Our purpose in presenting this material is to bring to the

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* Research Engineer, Special Developments Group, Scientific Support Division.

attention of engineers background material which they would not normally encounter in the course of routine development work. An excellent and timely reference is as follows: *Seminar on Methods of Detection, Measurement and Monitoring of Pollutants in the Marine Environment.* The international seminar was organized by FAO with the support of UNESCO, IAEA, SCOR and WMO, and was held in Rome, Italy, Dec. 4–10, 1970. The final report, the title of which was given, is a very thoroughgoing document and certainly a must reference for anyone seriously considering the development of sensors for pollution measurement. Perhaps it would be appropriate to present some exact quotations selected from the referenced document. The quotations follow:

1. "The pressures to develop sensitive and reliable methods come about when those responsible for the management of our environment need an objective evaluation of existing or potential perils." (p. 2)
2. "Nearly all of the Panels concerned with the contaminants identified specific examples of man's waste products which may be leaking to the environment in substantial quantities and *for which as yet there are no analytical techniques available.*" (p. 2)
3. "Very few analyses for organochlorine pesticides appear to have been carried out on sea water and the panel considered that the present methodology was not capable of detecting, on a routine basis, the quantities of these compounds in open sea waters." (p. 5)
4. "(This corresponds essentially to the ratio of useful data produced to the labour expended, since instrumentation costs in the long run become negligible)." (p. 17)

The above quotations refer largely to employment of analytical techniques which admittedly are often inadequate and may, of course, be prohibitively expensive. As mentioned earlier, we do not have sensors which we can substitute for the now essential analytical techniques. Further, it appears exceedingly dubious that we can hope to extrapolate simple engineering at present to make up for the deficiencies.

As far as actually putting a large-scale monitoring system into operation, all elements such as platforms, moorings, power supplies, data storage and processing, and radio telemetry are all available and would permit the immediate creation of a global system. However, as mentioned earlier, we simply do not have the very critical transducers which are so very essential. Panel 8 of the FAO Seminar considered the subject of "Test Organisms." Panel 8's report is exceedingly interesting, especially from the standpoint of ideas which might well make possible exploiting living organisms as sensors or sensor systems. A very great problem from the standpoint of a sensor mechanism is that it is necessary to measure such extremely dilute measurands. Conceivably, it would be feasible to utilize such organisms as mollusks, some of which possess the ability to amplify or concentrate for instance DDT from ambient water as much as 70,000 times that in the water supply. Furthermore, in many cases, this is a completely reversible mechanism in which the level of the tissue residue changes as the level of DDT changes in the ambient water. Under a section entitled, "Special Systems" the following is of great interest: "Consideration should be given to the use of bioaccumulators at ocean sites by holding them in or on devices attached to buoys, etc." Would it not be possible, with patience and ingenuity, to devise a "modular package" consisting of the bioaccumulator wired to a suitable integrated circuit, the whole fabricated as a plug-in sensor package?

Quite possibly appropriate bioaccumulators could be used as part of the sensor system to improve the sensitivity of the sensor itself since the sensor inserted in the tissue of the bioaccumulator would be "seeing" a much higher level of pollutant than if it were directly exposed to the environment. In this type of application the bioaccumulator in effect functions as a preamplifier.

Having introduced the possibility of utilizing whole organisms as part of a sensor system, it may be well to consider some organisms that already perform an almost complete sensor function in a way that we can utilize the output very readily. For instance, Dr. Theodor Bullock at the Scripps Institution of Oceanography of the University of California at San Diego, has some very interesting fish that send out a continuous electrical signal of around 1000 Hz which appears to be utilized for location purposes. The signal level is quite high and it may be readily picked up by simply putting two electrodes connected to a simple amplifier in the tank holding the fish. It has been observed that there are output frequency changes from the fish which respond to changes in concentration of heavy water. The fish assays heavy water with a sensitivity of about 0.01% and it is believed to be accurate to 0.1%.

There is another quite interesting line of approach to the matter of fabricating sensors that we will now consider, namely examining the feasibility of utilizing living bio-sensor mechanisms as part of our sensor package. Many marine organisms possess chemo-receptor mechanisms that respond to extremely low levels of chemicals some of which are pollutants. It is suggested that we might well be able to extirpate suitable chemo-receptor mechanisms complete with their afferent nerve to which we can attach microcircuit amplifiers and signal conditioners even with the power supply. The whole could be mounted in a suitable package with semipermeable membranes to permit passage of the measurand but to prevent the passage of undesirable bacteria and viruses. Suitable nutrient solution would need to be utilized properly buffered. It is proposed that cold-blooded systems be employed since their metabolic demands are minimal and further, and very significantly, the rate of accumulation of metabolites is extremely low and manageable. The complete package would in a sense be a bio-electronic sensor system.

There is no question but that a very great deal of research would need to be carried out in order to develop a viable and reliable system. Many of the chemo-receptor mechanisms represent the result of several millions of years of evolution and the sensitivities which they are capable of responding to appear to make them quite applicable to working successfully with extremely low concentrations to be anticipated in the marine area.

Pharmacologists have long known that it is possible to enhance the sensitivity of an existing chemo-receptor system by chemical means. Sometimes it is simply by introducing a chemical that delays the action of an enzyme.

It is interesting also to consider what could be done in the matter of changing the response characteristics of a given chemoreceptor mechanism once we understand the fundamental chemical mechanisms involved. It seems quite reasonable to anticipate that we may well be able to "sensitize" the chemo-receptor mechanism to make it respond to measurands which it heretofore was unable to respond to. This, of course, is by no means a new phenomena and it has been used for many decades in connection with photo emulsions. In this case, the photographic emulsions have been sensitized with proper chemical treatment and after the sensitization, they are then able to respond to wave lengths of light that they heretofore ignored. This suggests that we might well, once we understand the chemical mechanisms, sensitize selected chemo-receptors so that we can make them respond to pollutants and other substances in a tailor-made fashion.

One of the by-products of the research which would undoubtedly be necessary to develop chemo-receptor mechanisms into acceptable bio-electronic sensor packages, is the fact that the knowledge gained undoubtedly would be extremely useful via bionics to help us devise inanimate sensors of exceedingly high sensitivity to the desired pollutants which it is necessary to measure.