A NEW TURBIDITY METER FOR MONITORING THE QUALITY OF WATER

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ABSTRACT

The clarity of the water which is affected by the concentration of suspended particles is a measure of its quality. In this paper the design and fabrication of a turbidity meter is presented. Its operation is based on the principle that the intensity of the light scattered by the suspended matter is proportional to its concentration. Unlike the commercially available turbidity meters, which are relatively expensive and bulky, the proposed device is small-sized, lightweight, easy to use, reliable and inexpensive. This is achieved by employing a fiber link and a laser diode source. Moreover, its small size allows *in situ* measurements with satisfactory spatial resolution. It should be noted that the colour of the water does not affect the measurements with the new probe, which has a very good response to the changes of water turbidity. Laboratory tests of the device have yielded satisfactory repeatability and stability.

ΜΙΑ ΝΕΑ ΟΠΤΙΚΗ ΔΙΑΤΑΞΗ ΜΕΤΡΗΣΗΣ ΤΗΣ ΘΟΛΕΡΟΤΗΤΑΣ ΤΟΥ ΝΕΡΟΥ

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ΠΕΡΙΛΗΨΗ

Η διαύγεια του νερού, η οποία επηρεάζεται από τη συγκέντρωση των αιωρουμένων σωματιδίων αποτελεί μέτρο της ποιότητάς του. Στην εργασία αυτή περιγράφεται ο σχεδιασμός, η κατασκευή και η λειτουργία ενός οπτικού αισθητήρα μέτρησης της διαύγειας των ρευστών, που στηρίζεται στο γεγονός ότι η ένταση της σκεδαζόμενης από τα αιωρούμενα σωματίδια ακτινοβολίας είναι ανάλογη της συγκέντρωσής τους. Σε αντίθεση με τα συνήθη θολερόμετρα, που έχουν υψηλό κόστος και μεγάλο σχετικά μέγεθος, η προτεινόμενη διάταξη έχει χαμηλό κόστος, είναι μικρή σε μέγεθος, ελαφριά, αξιόπιστη και εύχρηστη. Αυτό επιτυγχάνεται με τη χρήση συστήματος οπτικών ινών και πηγής laser. Το μικρό της μέγεθος επιτρέπει *in situ* μετρήσεις με ιδιαίτερα ικανοποιητική χωρική διακριτική ικανότητα. Επιπλέον οι μετρήσεις είναι ανεξάρτητες του χρώματος του ρευστού. Οι δοκιμές στο Εργαστήριο έδειξαν ότι η διάταξη αποκρίνεται ταχύτατα στις μεταβολές της διαύγειας του ρευστού με πολύ καλή επαναληψιμότητα και σταθερότητα.

1. INTRODUCTION

Reliable monitoring of the water clarity, which is a measure of suspended particle concentration in natural streams (rivers, lakes etc.) and in industrial plant waters (process streams, effluent) has been a persistent practical problem. The clarity of water and consequently the suspended particle concentration is measured by turbidity probes.

Turbidity is an expression of the optical property of a medium, which causes light to be scattered and absorbed rather than transmitted straight through a sample. The medium concerned is usually water in which light is scattered by suspended particles. Turbidity is defined by the International Standards Organization (ISO) as the "reduction of transparency of a liquid caused by the presence of undissolved matter". It is measured using the techniques of turbidimetry or nephelometry and is expressed in arbitrary units (Nephelometric Turbidity Unit, NTU). The direct relationship between turbidity data and suspended solids concentration depends on many factors, including particle size distribution,particle shape and surface condition, refractive index of the scattering particles and of the suspension medium and wavelength of the light [1].

There are three basic designs of turbidity meters [1]:

- the *nephelometer*, which measures directly the intensity of light scattered by the sample. The light intensity is directly proportional to the amount of matter suspended in the light path.The sensor is mounted at an angle (usually 90^o) to the traversing beam to record scattered light. Nephelometers usually provide greater precision and sensitivity than turbidimeters and are normally used for samples of low turbidity containing small particles.
- the *turbidimeter*, sometimes called absorption meter, which measures the intensity of the beam after it has passed through the sample. Suspended matter in the light path causes scattering and absorption of some light energy. The transmitted light is detected, in relation to initial beam intensity. Turbidimeters are more appropriate for relatively turbit samples in which the scattering particles are large in relation to the light wavelength used.
- the *ratio turbidimeter*, in which both transmitted and scattered light is detected. For this purpose, transmitted light and 90^o-scattered light are measured simultaneously with two different photocells, which produce two voltages, V_0 and V_{90}, respectively. Changes in the light absorption of the process medium, e.g. because of colouring, have the same influence on both photocells. Thus, the signal ratio, $R=\frac{V_{90}}{V_{90}+V_0}$ remains unchanged. This feature has a number of advantages, including the elimination of the effect of sample colour on readings and the increase of the long-term stability of the instrument (by reducing drift). This design appears to be more appropriate for liquids either strongly coloured or of variable colour concentration, and for samples of high turbidity.

Continuous turbidity monitoring has become increasingly popular, mainly because the alternative practice of sampling and sedimentation analysis or filtration-and-weighing procedures are time-consuming and error-prone. In remote environments, a likely scarcity of suitable local laboratory facilities underlines the need for an appropriate field-oriented method [3]. Turbidity probes may also be the only viable means of assessing suspended sediment changes in circumstances where conditions are harsh and access is limited. Generally, the turbidity values can serve as a simple and convenient measure of the concentration of suspended solids (sulfates, particulate iron, carbon etc.) in water-supply and waste-water management installations [1].

The relatively high price of commercially available turbidity meters spurred intensive research on designing an inexpensive turbidity sensor, which would be reliable, with high frequency response and good spatial resolution, but at the same time easy to fabricate, portable and robust, thus suitable for field measurements. Of the various turbidity probe designs, optical units have been the most widely used [4, 5]. More recently, the optical probes utilizing light in the visible wavelengths have been replaced by probes utilizing infrared sources and detectors. The change of detection technique has also been accompanied by upgrading and miniaturizing the electronics to allow amplification of signals within the sensor head [3].

The purpose of this project is to design and construct a portable, inexpensive and reliable ratio turbidimeter for field measurements.

2. DESIGN AND CONSTRUCTION

In commercially available instruments, both the light source and the photodetector are usually located inside the sensor housing [6]. In order to reduce the probe size and at the same time to minimize interference with the water, a first attempt was made to place the electronic parts away from the probe. For this reason, the detector and the light source were placed in the same unit and both the incident and the reflected light were transmitted using optical fibers. The latter, among other attractive features, have small dimensions and light weight, excellent resistance to corrosive environment (because they are made of glass or plastic) and have practically no inductive interference [6].

However, because the intensity of the light reaching the photocell is generally low, even a small attenuation of the transmitted light would greatly affect the sensitivity of the measurements. Therefore, in the final design and in order to improve the performance of the measuring device, the light detector had to be embodied in the probe.

The measuring system under discussion is comprised of two subsystems, the optical sensor (probe) and the signal conditioning unit (analyzer). The light source, which is located in the analyzer housing, emits light, that is transmitted by an optical fiber, passes through an optical sensing gap and reaches the two photocells (one for the transmitted light and another for the 90^0 scattered light). The electrical signals produced are processed by an electronic circuit described elsewhere [7]. The value of the resulting voltage is displayed on a digital meter.

The probe is a Plexiglas cylinder whose length is 3 cm and its diameter 2 cm (Figure 1). The optical sensing gap is 1 cm long (Figure 2). The optical fiber connector (3 mm diameter) and the detector-1 (4 mm wide) are mounted along the axis and on the opposite sides of the cylinder. The detector-2 (side-detector; 4 mm diameter) is mounted at an angle of 90º with respect to the light path. Both detectors output-cables are incorporated inside the cylinder. Silicone rubber is used to insulate the electrical system and to prevent water interference.

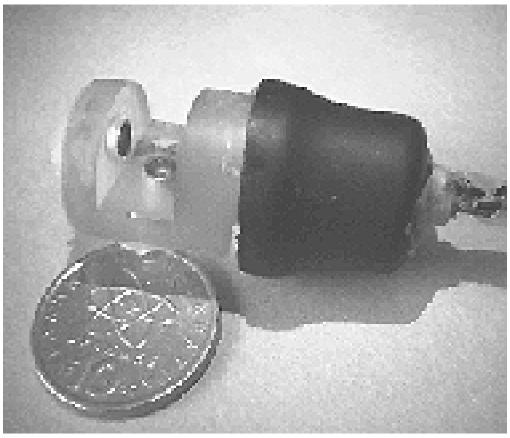

Figure 1. Photo of the probe

The main body of the prototype probe was made of Plexiglas, a material easy to handle and resistant to most environments. The main body can also be fabricated using any other material compatible with the liquid to be measured (e.g. stainless steel). The optical fiber used is plastic of 1 mm diameter. Wherever plastic is considered unsuitable, glass fibers can be used instead.

Light Emitting Diodes (LEDs) are the most commonly used light sources in optical probes but they emit low intensity light. In our case, the light must have a high directivity, in order to be transmitted through the fiber link and a relatively high intensity, because of the attenuation caused by the fiber. Since the LED output is low, a diode laser source of high directivity and relatively high light intensity is used to improve noise to signal ratio (NSR). The LASER used (FLDM-4) is a 5 mW semiconductor laser that produces red light (670 nm) and has a low power consumption.

The photodiode converts incident light directly into electrical energy. The light-sensitive cell used is the BPX 65 photodiode (SIEMENS), which has a spectral sensitivity ranging from 400 nm to 1100 nm and is hermetically sealed in a waterproof and reasonably robust case.

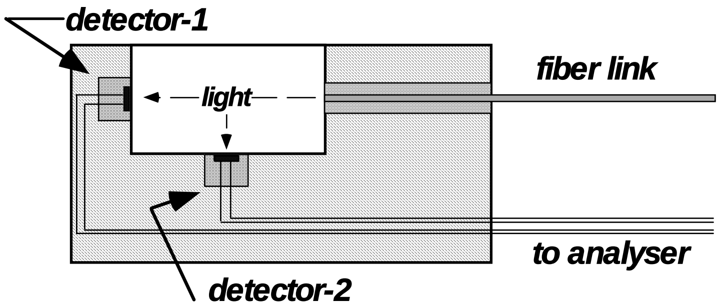

Figure 2. Schematic of the probe

The analyzer houses the laser source and an electronic circuit, which amplifies the low intensity signal of the photocells, performs the necessary calculations and displays the resulting signal on a digital multimeter. The signal needs further conversion to be transformed to turbidity values. The analyzer can also be connected to recorders, data-loggers and alarm systems. A special connector links the optical fiber to the laser source. The special cable linking the probe to the analyzer, includes the optical fiber and the two electrical wires connecting the photocells to the corresponding amplifiers. Details of the analyzer are described elsewhere [7].

The components for a complete turbidimeter cost approximately $150, which is an order of magnitude less expensive than commercially available turbidity meters [4].

3.PROBE CALIBRATION AND TESTING

An *indirect* method for the probe calibration was employed, in order to avoid the use of the carcinogen formazin, a method which is considered the common practice [1]. Thus, the sensor was calibrated against a latex colloidal dispersion (DOW xz 95065.00) containing monodispersed polystyrene particles (D=400 nm), that was added to distilled water to produce a 550 ppm stock suspension.

The calibration procedure is as follows:

- The stock solution is progressively diluted to produce several samples (down to 0.76 ppm).
- The turbidity of each sample is measured both with the new probe (Figure 3) and a commercial turbidimeter (Hach 2100A) used as reference (Figure 4). The zero-turbidity value is defined in pure distilled water.

The calibration curve (Figure 5) is produced by combining the results of the above measurements and it relates the output R of the analyzer to the turbidity value (NTU).

Three colourless samples with turbidities 240, 700 and 820 NTU were coloured by gradually adding a Methylene Blue dye (Merk), and the corresponding R values were measured. Methylene Blue was chosen because its maximum absorbance occurs at the wavelength of the Laser source used. Figure 6 shows that the concentration of the dye, C_d, has practically no influence on the response of the probe.

The repeatability of the instrument was checked by conducting a series of 3 sets of experiments and the results were satisfactory, as shown in Figure 3.

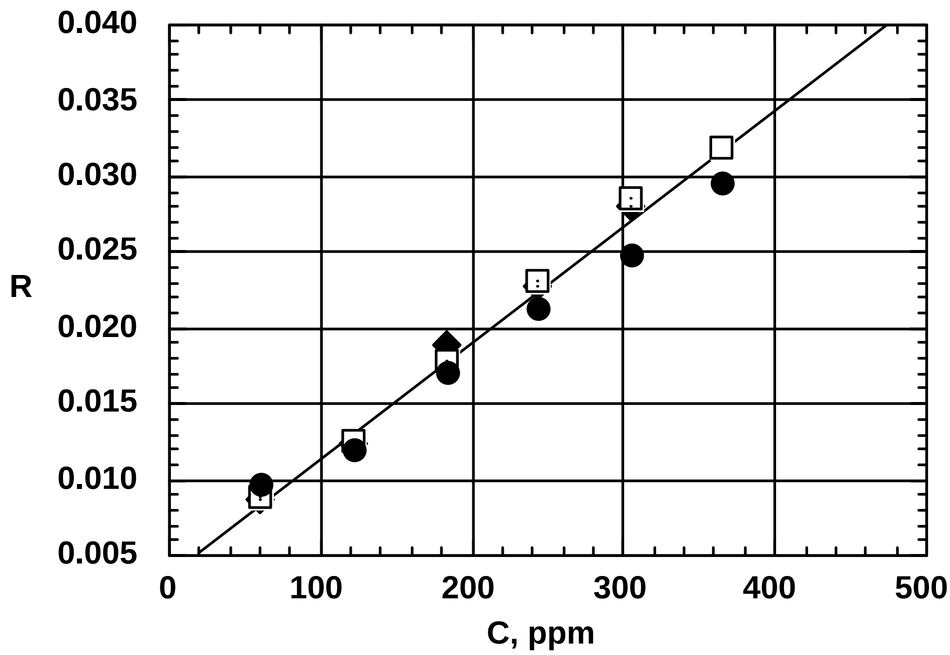

Figure 3. Repeatability test of R vs. particle concentration (3 sets of experiments).

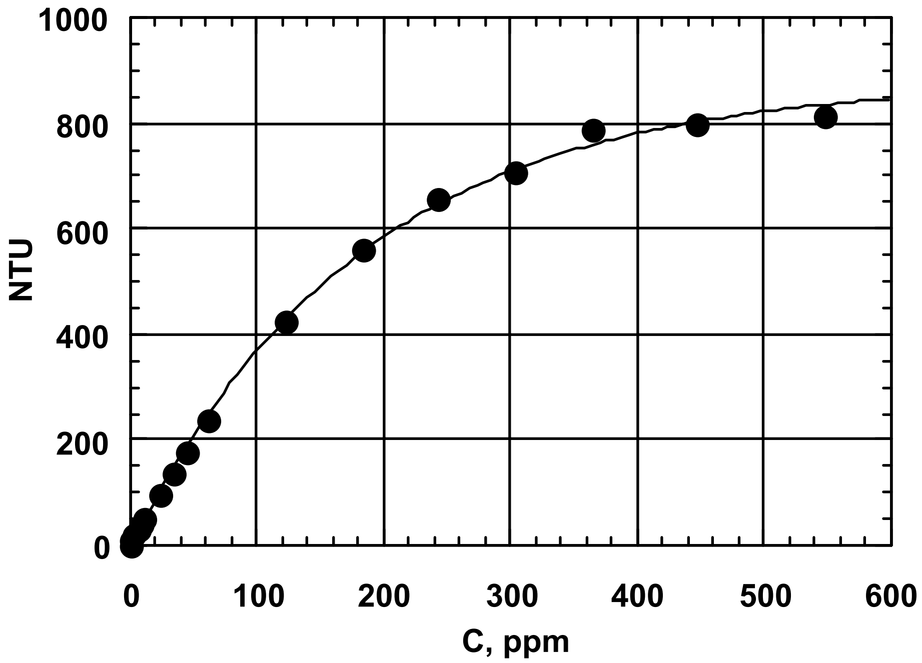

Figure 4. NTU vs. particle concentration.

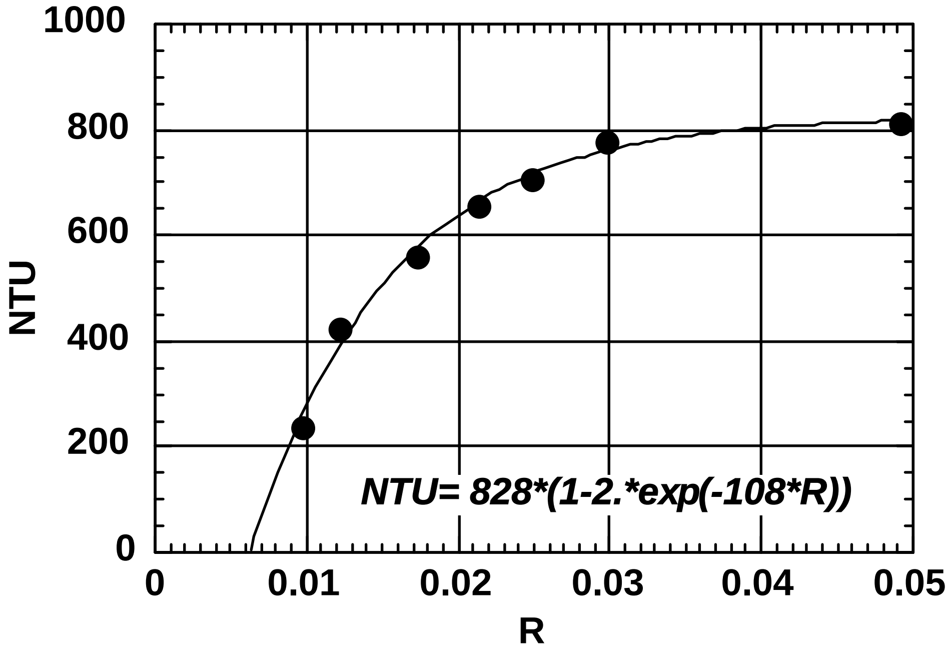

Figure 5. Calibration curve of the new probe.

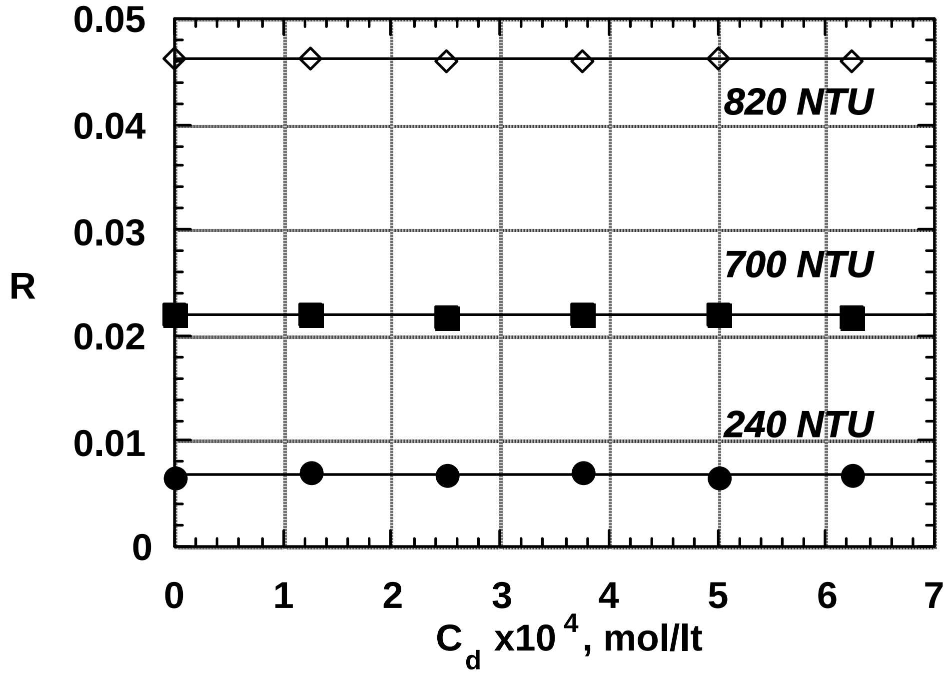

Figure 6. Effect of colour on the ratio R; C_d: Methylene Blue dye concentration.

4. CONCLUDING REMARKS

The proposed measuring system appears to be suitable not only for continuous monitoring of natural waters but also for process monitoring and control of industrial and municipal water-treatment plants.

The prototype version of the device is quite appropriate for turbidity measurements in the range 200 to 800 NTU, as shown in Figure 5. Below 200 NTU the accuracy of the device deteriorates and measurements are not considered reliable, whereas above 800 NTU the curve is practically flat and insensitive to turbidity variations. To remove this limitation for higher NTU values (very dense dispersions) a probe with a smaller sensing gap should be used, because light attenuation is directly proportional to the light path. Similarly, for low turbidity measurements a probe with a greater gap is needed. Since the total cost of a probe is small (less than $5), several probes can accompany the analyzer for use in various environments.

The use of optical fibers renders the device flexible and lightweight, thus portable, allowing in situ measurements with very good spatial resolution. For experiments where an even better spatial resolution is needed and the medium is colourless, a simpler version of the proposed probe can be constructed. In this case only the detector-1 of the probe is employed and the instrument functions as a simple turbidimeter, which measures only the attenuation of the initial incident beam. Details of the device are found in the cited literature [7].

Both the LASER source and the signal conditioning have very low power requirements. Therefore, batteries can be used to power a portable analyzer. To further reduce power consumption automatic sensor-excitation facilities can be used to switch on the LASER only during measurements.

Unlike some commercial turbidimeters, the proposed instrument is not equipped with a self-cleaning mechanism. If the instrument is not used in heavy loaded suspensions, a water shower is adequate to clean the sensor from the impurities deposited during the measurements.

The device is of low cost and easy to fabricate. The construction materials are easily accessed and the final cost of the whole device does not exceed $150. Its response time to turbidity changes is limited only by the response time of the electronic circuit. In general the device is considered suitable for continuous measurements, provided a clean sensor is maintained.

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