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Ancillary device for flow rate measurement using dye tracer technique

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ABSTRACT

Dye tracer technique is a successful tool for measuring liquid flow in closed conduits and open channels. The technique is based on the continuous injection of a tracer into the flow and on the measurement of the dilution ratio. As one of the requirements, the tracer injection rate must be known and well controlled. A device was designed to obtain this control. Such device implements a volumetric flow measurement technique and provides accurate digital display readout. Experimental results indicate that the apparatus can be used to measure the injection flow rate in a range from 235 to 2000 ml min^{-1} with a relative error smaller than 1.5% of the reading. Even with these low injection flow, the dilution method can be applied to determine the much higher flow rates typically found in domestic or industrial outfalls as well as in artificial or natural channels. This paper also presents an application of the dilution method to flow rate measurement of an industrial outfall and the uncertainty analysis associated with the obtained values. The results indicate that the main errors of discharge estimation can arise from non-steady state flow conditions, incomplete tracer mixing, uncertainty of tracer concentration and tracer injection rate measurements.

1. Introduction

In the Hydraulic Engineering field, the measurement of effluent dilution is essential when monitoring submarine outfalls in coastal waters during the operational phase [1,2].

Under typical operational conditions, the effluent dilution field can be determined in situ using artificial tracers techniques [3,4] and is useful for impact assessment and regulatory purposes. Tracing techniques and the application of the dilution method also allow the indirect calculation of effluent flow rate.

The measurement of flow rate by the dilution method is known since the nineteenth century [5] and is well-established [6,7].

The application of the dilution method for measuring liquid flow in closed pipes is described on the international standard ISO 2975–2 [8]. The constant-rate injection technique for discharge measurement in open channels is described on the international standards ISO 9555–1 [9] and ISO 9555–4 [10]. ISO 9555–4 [10] deals with the specific use of dye tracers, which is the approach of this paper.

1.1. Applications of the dilution method

Using the dilution method, a tracer is continuously injected into the stream and the flow rate is determined by the tracer dilution downstream.

The section of ISO 2975–2 [8] on error determination states that about 1% flow rate measurement accuracy can be obtained provided that the mixing of the tracer with the effluent is of equivalent accuracy and that the injection flow rate is measured with a better accuracy. However, Turner [11] claims a typical accuracy of $\pm 2\%$ for flow rate measurement by the dye dilution method using careful procedures.

These high accuracy measurements can be used [12] to: (i) calibrate and routinely check flow meter devices that present typical measurement errors up to $\pm 20\%$; (ii) test of pumps and other flow equipment [7] as a way to check performance and measure efficiency of the equipments; (iii) determine flow rate of process water launched into natural systems; (iv) verify the flow rate of wastewater treatment plants under operational conditions.

The dye dilution technique was used by Smith and Kepple [13] to measure sewage flow and localizing infiltration in a municipal collection system.

The dilution method is also adequate to measure flows that are difficult to access [12] or in cases when velocity-area discharge measurements result in inaccurate values [19].

1.2. Related study

Flow rate measurement at urban sites using conventional methods is a difficult task at stations with accessibility problems,

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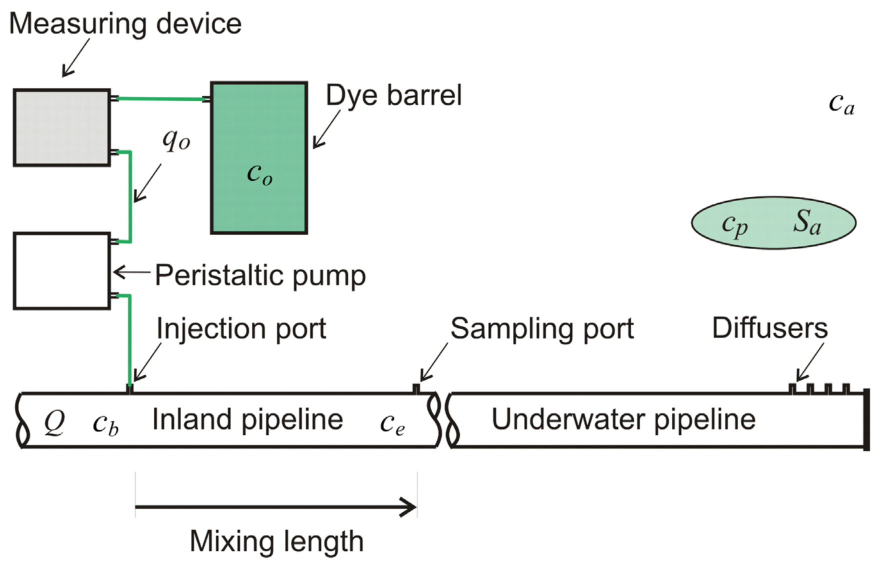

Fig. 1. Aspects of the application of the dilution method for wastewater flow measurement and detection of the dilution field of an outfall with the help of an ancillary flow measurement device.

under rainfall conditions, and under conditions of rapid stage variations. The design and operation of systems to measure and monitor the flow of sewage water deserves special attention and care [14,15]. Knowing water flow can help the management and maintenance of combined sewer system [16].

Duerk [17] implemented an automated constant-rate dye dilution technique to measure discharge at urban gaging stations under varying flow conditions. The study by Duerk [17] utilizes an injection system and a recovery system (an automatic water sampler). The results showed that the discharges calculated by the dilution method were within ± 10 percent of the discharges calculated from current-meter measurements. The constant-rate dye dilution method is reported [17] as the most accurate method for unsteady flow and it has the lower total cost.

Based on Duerk's work [17], Soenksen [18] designed an automatic system to measure stage and discharge on small streams. Discharge measurements were carried out by the constant-rate tracer-dilution method and were used to develop rating curves. The automatic system included components for stage recording, tracer injection, stream sampling, and sample analysis. Except for sample analysis, which was done in the laboratory, the other components worked on site.

The automated system developed by Clow and Fleming [19] utilizes data loggers at both injection and sampling sites to collect data from sensors, control system operations and perform calculations. At the injection site, a dye tracer solution was injected into the stream for 60 min at a constant rate using a metering pump which drew solution from a cylindrical column. The dye solution in the column was replenished after each injection cycle by opening a solenoid valve, which allowed solution to flow into the column from a storage barrel. The injection flow rate was calculated from the column head drop, measured by a pressure sensor, during the injection cycle. At the sampling site, a submersible fluorometer measured in situ dye concentrations data relayed to the injection site via radio. Flow rate was then calculated by the upstream data logger using Eq. (2).

The ancillary device described in this paper was developed by Fernandes for obtaining the BSc degree at Federal University of Rio de Janeiro (Circuitry for liquid flow rate measurement and control [in Portuguese]) during the year 2000 and presents some similar concepts to that proposed by Clow and Fleming [19].

Naturally, other techniques like those that use acoustic devices [20] can be used for flow rate measurement in outfalls. However, the dilution method has the additional feature of determining the dilution field in receiving waters.

2. The dilution method

The dilution method for liquid flow measurement relies on the injection of a tracer solution into the flow and on the discrete sampling at a control section for measuring the tracer concentration [6,21,32]. The flow rate is determined by the tracer dilution downstream.

The application of the method requires some basic conditions: (i) use of a conservative tracer, meaning there is no sink or source; (ii) the tracer concentration and its injection rate are constants during the measurement; (iii) steady state flow during the measurement; and (iv) complete mixing – improved by turbulence – of the tracer in the flow before the tracer reaches the sampling point.

Assumption (i) will be checked after testing solutions prepared with effluent samples, as described in Section 2.2 Dye tracer measurement. Assumptions (ii) and (iii) are, at this time, expected to be true as tracer concentration is controlled by the operator, injection rate is measured and controlled by the electronic system described in this paper and, as another condition, constant flow rate is expected for industrial outfalls working under typical production scenario. The basic assumptions of constant injection rate and effluent flow rate will be assessed with a testing procedure carried out on the field experiment results and presented in Section 6. Results and discussion. Condition (iv) is easily obtained as inland pipeline has a diameter on the order of meter and sampling port is typically located some hundred meters after the injection port; in such way, we do not need to refer to mixing length calculations.

Fig. 1 depicts the general ideas behind the method in which a dye tracer solution of known concentration c_o is injected into the effluent by a pump whose flow rate q_o is obtained by a measuring device. After a mixing length, samples are collected for measuring the dye concentration c_e in the effluent. Then, the effluent flow rate Q is calculated by the dilution method described hereafter.

At the end of the underwater pipeline, a set of ports or diffusers launch the effluent in the ambient water. Samples of tracer concentration c_p in the diluted plume allow the mapping of the

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