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Flow rate measurements in a canal and large diameter pipelines using radiotracer dilution method

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ABSTRACT

Flow rates of water were measured in four different sections of an irrigation canal and in large diameter pipelines in a thermal power plant using radiotracer dilution method. Iodine-131 in the form of sodium iodide was used as radiotracer for the measurements. The flow rates of water were measured at four different pumping stations along the canal and ranged from 20.30±0.29 to 20.62±0.26 m^3/s when single Concrete Volute (CV) pump was operated. The measured flow rates were found to be in agreement with the theoretically estimated pumping capacity of the CV pump, i.e. 20 m^3/s. In case of the flow rate measurements in large diameter pipelines, the flow rate was measured to be ranging from 14.10±0.43 to 15.43±0.46 m^3/s with single Vertical Turbine (VT) pump in operation and 24.55±0.78 to 27.51±0.82 m^3/s with simultaneous operation of the two identical VT pumps. The values of flow rates shown by the installed flow meters were found to be lesser than the values measured by the radiotracer dilution method.

KEYWORDS

Flow rate, canal, large diameter pipeline, Concrete Volute pump, Vertical Turbine pump, radiotracer dilution method, Iodine-131

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1. INTRODUCTION

Measurement of flow rates of fluids is an essential requirement in industrial and environmental systems. Different conventional methods are available for measurement of flow rates in pipelines, canals and rivers. However, in some specific industrial situations, it is not possible to measure the flow rates of the process material accurately using conventional methods. In such situations, radiotracer dilution method is very useful because of its higher detection sensitivity (10^{-9} mg/cc) [1-5]. Radiotracer dilution method is often used as a complementary method for flow rate measurement for calibration of installed flow meters as well as for evaluation of pumping efficiency of large capacity pumps. The present paper describes application of radiotracer dilution method for flow rate measurements of water in four different sections of an irrigation canal and in large diameter pipelines (dia: 3.6 m) meant for transporting cooling water in a thermal power plant. The main objectives of the flow rate measurements were to validate the pumping efficiency of the pumps used for pumping the water and calibration of installed flow meters.

2. PRINCIPLE OF RADIOTRACER DILUTION METHOD

The principle of radiotracer dilution method is shown in Fig. 1. In the radiotracer dilution method, a tracer solution of known concentration (C_1) is injected into the flow stream at a constant rate (Q_1) for a particular duration of time. Samples are collected from a sufficiently downstream location, where the tracer is completely mixed across the cross section of the flow stream. The minimum distance required for the radiotracer to mix uniformly across the cross-section of the flow stream is known as the mixing length. The tracer concentration (C_2) in the collected samples is measured.

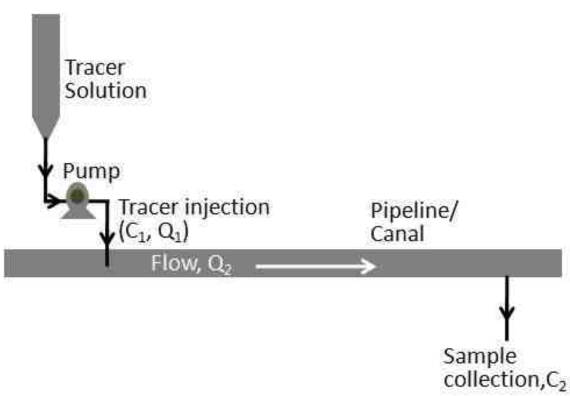

Fig.1. Principle of radiotracer dilution method

Let initial background radiotracer concentration in the water before tracer injection is C_0.The discharge rate (Q_2) of the flow stream is calculated by following tracer balance equation [6,7].

$$Q_1C_1 + Q_2C_0 = (Q_1 + Q_2)\, C_2$$

$$\text{Since } Q_2 >>> Q_1\text{, Hence, } Q_1 + Q_2 = Q_2$$

$$\text{Also, } C_2 >>> C_0$$

$$\text{Therefore, } Q_2 = Q_1 \times [C_1 / C_2] \qquad (1)$$

3. EXPERIMENTAL

3.1. Preparation of radiotracer

In both the cases, Iodine-131 (^{131}I) (gamma energies: 0.36 MeV (80 %), 0.64 MeV (9 %); half-life: 8 days) in the form of sodium iodide was used as radiotracer. The radiotracer was produced in two steps. In the first step, tellurium dioxide (TeO_2) powder was irradiated with thermal neutrons in DHRUVA nuclear reactor, Trombay, Mumbai, India to produce ^{131}I by $^{130}Te(n,\gamma)^{131}Te$ nuclear reaction followed by beta decay. In the second step, aqueous solution of ^{131}I in the form of NaI was prepared by dry distillation process. About 55 GBq activity of ^{131}I was used for each test in the flow rate measurements in the canal whereas, about 11-22 GBq activity of ^{131}I was used in each test for the flow rate measurements in the pipelines.

3.2. Flow rate measurements in the canal

The radiotracer dilution method was used for measurement of water flow rates in four different sections of Saurashtra Branch Canal of M/s Sardar Sarovar Narmada Nigam Limited, Surendranagar, Gujarat, India. Five pumping stations (PS1, PS2, PS3, PS4 and PS5) were constructed along the 104 km long section of the canal and used for pumping water. Figure 2 shows a typical pumping station. Each pumping station comprises of 5-6 identical Concrete Volute (CV) pumps. The flow rates were measured at four pumping station i.e. PS2, PS3, PS4, and PS5 with single pump in operation at each station. For each test, the radiotracer solution was prepared by diluting the radiotracer containing 55 GBq ^{131}I activitiy in a volume of 15 litre of water in a graduated cylindrical vessel. About 0.06% inactive potassium iodide and 0.3% of sodium thiosulphate was also added and homogeneously mixed within the solution to minimize the losses due to adsorption and evaporation, respectively. 20 ml of this solution was withdrawn, further diluted to a volume 20 L in three successive steps with a dilution factor of 10^7 and stored for the measurement of C_1. The prepared radiotracer solution was injected at the suction end of the pump at a known constant rate (Q_1) (Table 1). The samples for measurement of radiotracer concentration (C_2) were collected from a downstream location at which the radiotracer was expected to mix homogeneously within the entire cross-section of the canal. For the present case, the mixing length required for the radiotracer to mix homogeneously with the entire cross-section was estimated to be about 405 m. However, the samples were collected at a downstream location 1000-1500 m from point of injection, which is more than the mixing length. A typical location used for collecting the samples for the measurements is shown in Fig. 3. The radiotracer concentration in the injected solution (C_1), collected samples (C_2) was measured using a specially fabricated sampling vessel (20 L) mounted with a NaI(Tl) scintillation detector connected to a data acquisition system. The detector was set to record tracer concentration at an interval of 2 minutes during the sample measurement. Identical detection geometry and conditions were maintained during measurement of tracer concentration in injected solution (C_1) and samples collected from monitoring locations (C_2). Similar experimental procedure was adopted in all four flow measurement tests.

Fig.2: A typical photograph of the pumping station

Fig. 3: A typical photograph of the location used for collecting the samples

3.3. Flow rate measurements in large diameter pipelines

The flow rate measurements in large diameter pipelines were carried out in a coal based thermal power plant at M/s Hinduja National Power Corporation Limited (HNPCL), Vishakhapatnam, Andhra Pradesh, India. The plant has two units (Unit-1 and Unit-2) each of 520 MW capacity. Steam produced in the plant is fed into the steam turbine at high pressure and temperature for generation of electric power. The exhausted steam is condensed in condensers and fed back into the boiler for reuse. Sea water is pumped through two different pipelines, each of diameter 3.6 m, using Vertical Turbine (VT) pumps and circulated through the condensers for steam condensation. A schematic diagram of the experimental system is shown in Fig 4. There are two independent pumping stations for each unit and each pumping station has two identical VT pumps for pumping the sea water for cooling. The pumps, P1A and P1B are used for pumping water in Unit-1, whereas the pumps P2A and P2B are used for pumping the water in Unit-2. Four tests were performed with operations of P1A; P1A and P1B simultaneously; P2A; and P2A and P2B simultaneously for flow rate measurements.

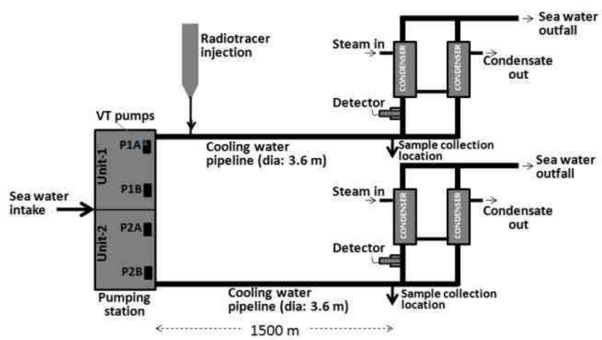

Fig.4. Schematic diagram of the cooling water circulation system and experimental setup for flow rate measurements at power plant

The radiotracer stock solution preparation and the tracer injection were carried out in a similar manner as mentioned in Section 3.2. In this case about 11-22 GBq activity of ^{131}I was used in each measurement. An aliquot of 20 ml was collected from the stock solution, further diluted to a volume 20 L in three successive steps with a dilution factor of 10^7 and stored for measurement of C_1. The samples for the measurements of tracer concentration C_2 were collected from a downstream location at a distance of 1500 m from the injection point. This distance was sufficient enough for the radiotracer to mix uniformly across the cross-section of the pipe. The concentrations of radiotracer in injected solution and in sample collected at downstream were measured as mentioned in section 3.2.

4. RESULTS AND DISCUSSION

For accurate measurements of the flow rates using radiotracer dilution method, several factors are to be taken into account, such as accuracy in the measurements of tracer concentration in the injected (C_1) and collected samples (C_2), dilution of aliquot drawn from the injected solution and injection rate of the radiotracer solution (Q_1). In addition to this, adequate care should be taken to mix the radiotracer homogeneously within the diluted volume and samples for the measurement of C_2 should be collected from a downstream location where the radiotracer is uniformly mixed within the entire cross-section of the flow stream [8,9]. Care should also be taken to minimize the loss of radiotracer due to adsorption and decomposition between the injection and sample collection location. All these factors were systematically addressed while carrying out the experiment and sample measurements. In both the cases, sufficiently longer mixing length than estimated from the analytical formulas was used thus minimizing the error due to inadequate mixing of the radiotracer. The aliquot collected from the injection solution was highly concentrated and; thus diluted in multiple steps to obtain the same level of dilution and statistical error as in the diluted sample (C_2). Adequate quantities of the inactive NaI and sodium thiosulphate were added to the injection solution to minimize the error arising due to the loss of the radiotracer. The concentration of radiotracer in the diluted sample collected from the injection solution and in the samples collected from the downstream location was measured at identical geometry to further avoid any error in the measurements. The results obtained from the flow rate measurements in the four pumping stations along the canal and in large diameter pipelines in the thermal power plant are given in Table 1 and Table 2, respectively.

Table 1: Results of flow rate measurements in the canal

Experiment 1 (Pumping station, PS2)			
Q_1 (ml/min)	**C_1 (Counts/ 2 min)**	**C_2 (Counts/ 2 min)**	**Q_2 (m^3/s)**
135	5.662×10^{10}	6275	20.30±0.29
Experiment 2 (Pumping station, PS3)			
156	9.304×10^{10}	11760	20.62±0.26
Experiment 3 (Pumping station, PS4)			
143.81	2.197×10^{11}	25811	20.47±0.22
Experiment 4 (Pumping station, PS5)			
144.07	1.0426×10^{11}	12179	20.60±0.37

Table 2: Results of flow rate measurements in large diameter pipelines

Experiment 1 (Unit-1, P1A)			
Q_1 (ml/min)	**C_1 (Counts/ 2 min)**	**C_2 (Counts/ 2 min)**	**Q_2 (m^3/s)**
188.2	5.867×10^{10}	11875	15.43±0.46
Experiment 2 (Unit-1, P1A+P1B)			
187.2	3.755×10^{10}	4240	27.51±0.82
Experiment 3 (Unit-2, P2A)			
220.8	3.096×10^{10}	8044	14.10±0.43
Experiment 4 (Unit-2, P2A+P2B)			
185.1	6.626×10^{10}	8291	24.55±0.78

5. CONCLUSIONS

The flow rate measurements in four different sections of a canal and in two large diameter pipelines were successfully carried out using radiotracer dilution technique. The flow rates measured at four pumping stations of the canal with a single CV pump in operation at each station were found to be ranging 20.30 ±0.29 to 20.62±0.26 m^3/s. Whereas, the theoretically estimated value of the flow rate produced by a single CV pump was found to be 20 m^3/s. The measured values of flow rates at four different pumping stations were found to be in good agreement with the theoretically estimated discharge rates of the respective pumps. The flow rate measurements in four different section of the canal helped the industry in early commissioning of the project, water budgeting and energy auditing leading to significant economic benefits. The values of the flow rates of cooling water in the pipelines of Unit-1 and Unit-2 of the power plant were measured to be 15.43±0.46 and 14.10±0.43 m^3/s, respectively when only one VT pump was operated in each unit. Whereas, the values of the measured flow rates were found to be 27.51±0.82 and 24.55±0.78 m^3/s, respectively when both the pumps were operated simultaneously in each unit. The values of the flow rates shown by the installed flow meters ranged from 12.5-16.5 m^3/s when only one pump was operated and 24-26 m^3/s when both the pumps were operated simultaneously. However, the theoretically estimated value of discharge rate produced by a single VT pump was found to be 15 m^3/s. The values of measured flow rates were found to be quite close to the theoretically estimated values but were found to be significantly different from the values shown by the installed flow meters. Therefore, the installed flow meters needed to be recalibrated. The accurate measurement of the flow rates helped the power plant to estimate the exact quantity of cooling water being used for condensing the steam and also evaluate the efficiency of the heat transfer in the condenser.

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REFERENCES

[1] Smith, D.B.,1964, River flow Measurement using Radioactive Tracers.

[2] Dilution Techniques for Flow Measurement, Bulletin, No. 31. Paper 8, Dept. of Civil Engineering, Univ. of Newcastle, Newcastle, New South Wales, Australia.

[3] British Standards Institution (1967) Methods of measurement of liquid flow in open channels. Part 2. Dilution methods. 2C. Radioisotope techniques. BS 3680 Part 2C, London.

[4] Florkowsi, T., Davis, T.G., Wallander, B. and Prabhakar, D.R.L., 1969, The measurement of high discharges in turbulent rivers using tritium tracer, J. Hydrol., 8, 249-264.

[5] International Atomic Energy Agency, 1968. Guidebook on nuclear techniques in hydrology. Tech. Rep. Ser. No.91, IAEA, Vienna.

[6] Charlton, J.S . 1986, Radioisotope tracer techniques for problem solving in industrial plants. Leonard Hill, Glasgow and London.

[7] International Atomic Energy Agency (1990) Technical report series No. 316, Guidebook on Radioisotope Tracers in Industry, Vienna, Austria.

[8] International Standards Organization, ISO 2975-3:1976, Measurement of water flows in closed conduits-tracer methods-Part III, Constant rate injection method using radioactive tracers, Geneva, 1976.

[9] Rimmar, G.M., 1960, Use of electrical conductivity for measuring discharges by the dilution method, National Engineering Laboratory Translation No.749, Trudy GGI, 36 (90), 18-48.

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