

FLOW RATE DETERMINATION FOR OPEN CHANNEL FLOWS BY USING RADIOTRACER BALANCE METHOD*

A. B. TUGRUL, N. ALTINSOY

*Nuclear Applications Division, Institute For Nuclear Energy
Istanbul Technical University (ITU), 80626, Maslak, Istanbul, TURKEY*

INTRODUCTION

An important application for radioisotopes is the "radiotracer technique" which are extraordinarily successful in almost all branches of science. An extremely small quantity of radioisotopes in a certain element makes it easy to trace this substance by its activity. This is the reason for the wide use of radiotracers. Hydrological problems are frequently very complex and many different techniques have to be applied for their investigation. Some of them can only be investigated by means of radioactive tracers. One of the basic application field of radiotracers in hydrology is measuring the flow rate of a watercourse. Many requirements of flow-rate measurements can only be given by means of radiotracer techniques.

In this study, it was aimed to determine the volumetric flow-rate in the open channel by using a radiotracer method. There are several radiotracer techniques that can be used for flow-rate measurement in an open channel. One of them is Radiotracer Balance Method (RBM) which was used in the experiments for the flow-rate measurement. The Radiotracer Balance Method is based on the principle of conservation of tracer. The tracer solution is injected at a constant rate into the flow to be measured and samples are taken at a point downstream.

METHOD

The radiotracer balance or total count method is based on the principle of conservation of radiotracer. It is assumed that if amount A of tracer is injected then this amount must eventually pass any downstream detection point [1, 2]. Mathematically this can be stated as:

$$A = \int_{x=0}^X \int_{y=0}^{Y(x)} \int_{t=0}^{\infty} C(x, y, t) \cdot v(x, y, t) \, dx dy dt \quad (1)$$

where $C(x, y, t)$ is the radiotracer concentration at the detection point at positions x and y on the fluid cross-section at time t and $v(x, y, t)$ is the net linear velocity at the same point and time. Volumetric flow rate at time t which is desired is given by:

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$$Q(t) = \int_{x=0}^X \int_{y=0}^{Y(x)} v(x, y, t) dx dy \quad (2)$$

Two assumptions are necessary for the volumetric flow rate calculation from the conservation of radiotracer relationship [2]. These are:

1. The linear velocity depends only upon position and is independent of time and
2. The radiotracer concentration is independent of lateral position and depends only upon time.

In this case Eq. 1 becomes:

$$A = Q \int_{t=0}^{\infty} C(t) dt \quad (3)$$

If the counting rate $R(t)$ is taken to be equal to the radiotracer concentration times a calibration factor F , then Eq. 3 becomes:

$$A = (Q/F) \int_{t=0}^{\infty} R(t) dt \quad (4)$$

The integral in Eq. 4 can be evaluated adequately by integrating to the finite time T and rearranging gives:

$$Q = \frac{FA}{\int_{t=0}^T R(t) dt} \quad (5)$$

The integral of $R(t)$ from $t = 0$ to $t = T$ is evaluated when a detector is connected to a scaler which accumulates counts from time 0 to T . If the integral of $R(t)$ from $t = 0$ to

$t = T$ is denoted N , then Eq: 5 becomes:

$$Q = FA/N \quad (6)$$

The conditions under which the tracer balance or total-count method do not require that the fluid be contained in a closed channel or a channel of constant cross-sectional area. Therefore, it should be possible to apply this method to the measurement of flow rate in open-channel streams and rivers [2]. For the calculation of calibration factor by using r is counting rate and c is radiotracer concentration [2];

$$F = r / c \quad (7)$$

EXPERIMENTAL STUDIES

For the measurement of open channel flow-rate by using RBM, an experimental set up has been constructed in the laboratory. This system consists of an open tank (channel of constant cross-sectional area), a flowmeter, a NaI(Tl) detector with counting system and a relaxation tank (Fig. 1). Selection of the labeling radioisotope is of primary importance in radiotracer experiments. Radionuclides identified so far include 58 natural and approximately 1300 artificial ones.

Most of them, however, are not always useful as radiotracers, mainly because of difficulties in preparation, undesirable half-life time and inadequacy of radiation for quantification [3]. Water solubility is also an important factor in choosing of the radioisotopes and their compounds. For labeling water and aqueous solutions, water soluble salts of the isotopes are advantageous [4, 5].

In the experiments Sodium-24 radioisotope was preferred as radiotracer due to its appropriate half-life which is preferable less than one a day, its availability and cost in addition to the water solubility. Irradiation conditions were investigated for the selection of suitable sodium compound [6]. Carbon can not be activated and I-131 does not undergo (n, γ) reaction. Half-life of oxygen is very short especially than the chlorine (Table: 1).

Table 1 Properties of Sodium and Combined Elements

Element	Half-life	Energy (KeV)	Abundance (%)	Thermal Neutron Cross-section for (n, γ) Reaction (Barns)
Na-24	15 h	1368.60	100.00	0.513
		2754.00	99.94	
O-19	26.91 s	197.14	95.90	0.00016
		1356.84	50.40	
Cl-38	37.24 min	1642.69	31.00	0.423

So, it was decided that the sodium carbonate (Na_2CO_3) is the most appropriate compound for the experiments due to its easy availability in addition to irradiation properties of compound elements except sodium [7]. Therefore only Na-24 is an active isotope in the sodium carbonate after 144 seconds of irradiation. That is desirable for the radiotracer applications. Sodium carbonate was irradiated in the TRIGA Mark-II Training and Research Reactor in the Istanbul Technical University, Institute for Nuclear Energy. Neutron flux of irradiation was 8.1×10^{12} neutron/cm² s.

The problem of how much radiotracer can be injected from the radiological safety point of view has been treated by Gardner [1]. The allowable maximum amount of injected tracer is:

$$A_{\max} = \frac{2 a \sqrt{\pi k x} \text{ (MPC)}}{\sqrt{u}} \quad (8)$$

where $A_{\max}$ is the allowable maximum amount of injected tracer, a is the average cross-sectional area of the stream, k is the dispersion coefficient, x is the distance along the stream that is under the control of the experimenters, u is the mean linear velocity of the stream and MPC is the maximum permissible concentration of the radioisotope being used.

A normal solution which contains 1 g molecular weight of the dissolved substance divided by the hydrogen equivalent of the substance per liter of solution was prepared in 10 cc after the irradiation of sodium carbonate [8]. The specific activity of sodium was 1.86 MBq/g and approximately 0.4 MBq activity was used for each experiment.

RESULTS AND DISCUSSION

Calibration factor for the experiment was obtained by determining the detector response for a known tracer concentration. Flow-rate which is 8.3 cm³/s, was calculated by using the net total count (after subtracting the background) and calibration factor (Table 2).

Table: 2 Experimental Results

Experiment	Calibration Factor (Counts/sec)/(Bq/cm ³)	Calculated Flow- rate (cm ³ /sec)	Error (%)
1	11.09x10 ⁻⁵	9,96	16,6
2	9.83x10 ⁻⁵	9,90	16.1
3	12.58x10 ⁻⁵	9,89	16.0

Obtained results were checked with the ratemeter and it was shown that the experimental data which were taken with RBM was very reliable and the average error was around 16% (Table: 2). Graphically evaluation of the experimental errors can be seen in Fig.2.

CONCLUSION

With this study; it is concluded that;

- Radiotracer Balance Method (RBM) is a preferable radiotracer technique due to applicability in dynamic flow conditions
- Error value is acceptable
- Error value has been almost constant

- Differences for the error values for different experiments are low
- It can be said that counting and scattering effect of the samples is the main reason of the error because of all of them is almost constant

So, it can be summarized that, the RBM can be used for flow rate determination of open-channel in-situ conditions, and the error value is acceptable and can be said that it can be drawn to down with the elimination of the counting and scattering effects.

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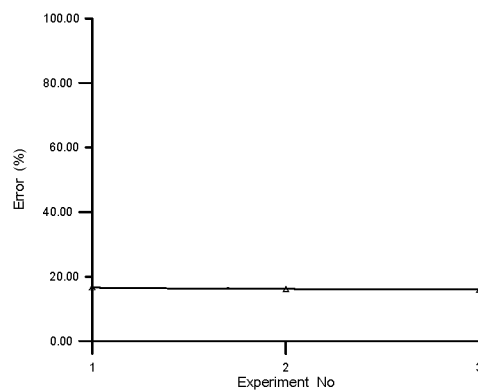


Fig. 2 Experimental Errors

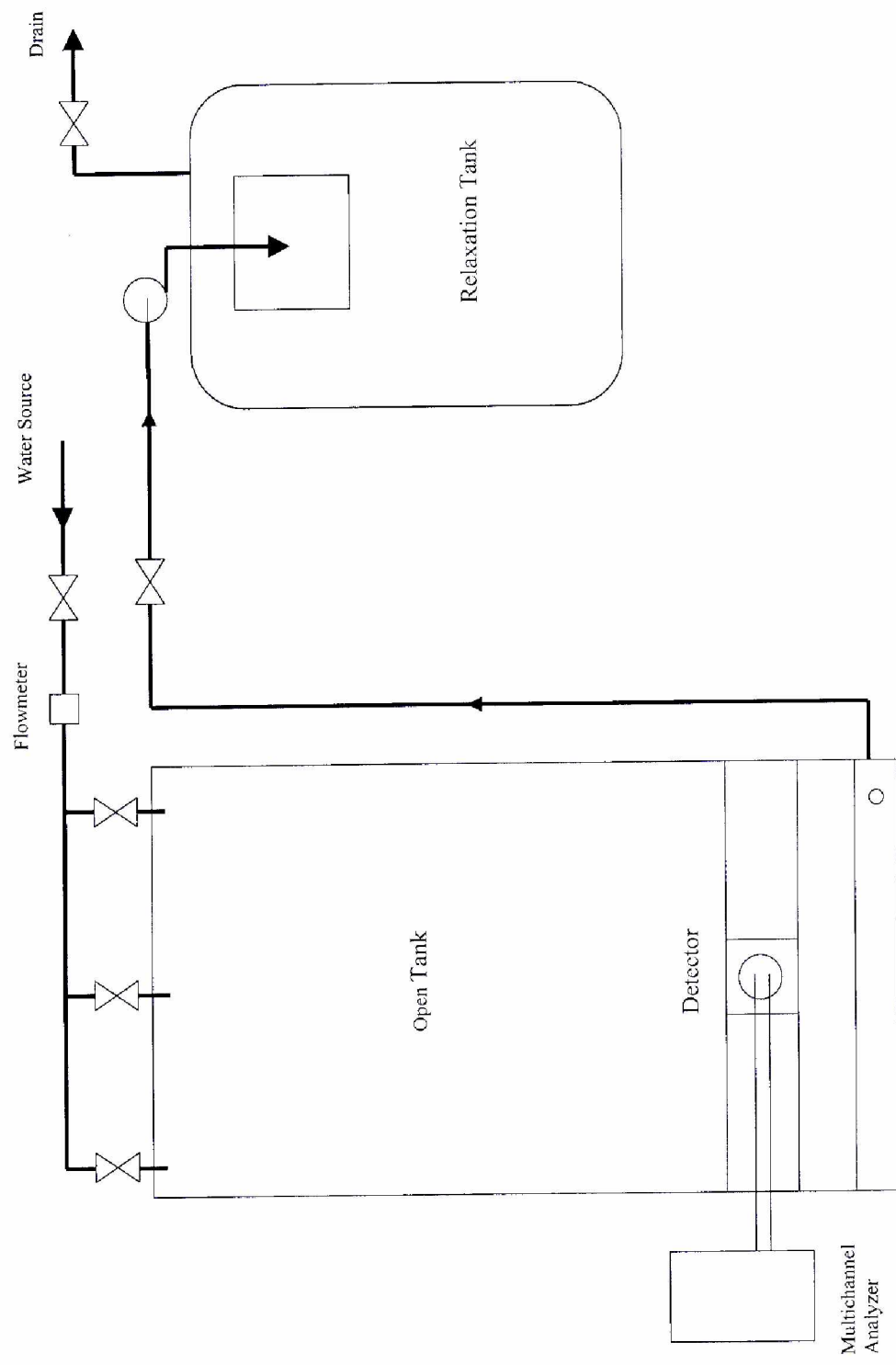


Fig. 1 Experimental Set-up