Preliminary study of the use of radiotracers for leak detection in industrial applications

S Wetchagarun¹, A Petchrak and C Tippayakul
Reactor Center, Thailand Institute of Nuclear Technology (Public Organization), Bangkok 10900, Thailand

E-mail: saensuk@tint.or.th

Abstract. One of the most widespread uses of radiotracers in the industrial applications is the leak detection of the systems. This technique can be applied, for example, to detect leak in heat exchangers or along buried industrial pipelines. The ability to perform online investigation is one of the most important advantages of the radiotracer technique over other non-radioactive leak detection methods. In this paper, a preliminary study of the leak detection using radiotracer in the laboratory scale was presented. Br-82 was selected for this work due to its chemical property, its suitable half-life and its on-site availability. The NH₄Br in the form of aqueous solution was injected into the experimental system as the radiotracer. Three NaI detectors were placed along the pipelines to measure system flow rate and to detect the leakage from the piping system. The results obtained from the radiotracer technique were compared to those measured by other methods. It is found that the flow rate obtained from the radiotracer technique agreed well with the one obtained from the flow meter. The leak rate result, however, showed discrepancy between results obtained from two different measuring methods indicating further study on leak detection was required before applying this technique in the industrial system.

1. Introduction

The radiotracer technique has been widely used for troubleshooting and process optimization in industry. According to IAEA, many developing countries have radiotracer application groups [1]. Thailand Institute of Nuclear Technology (TINT) is also interested in deploying the radiotracer applications especially in the petrochemical industry. The applications of interest include determining leak rate detection in heat exchangers or similar plant units or determining Residence Time Distribution (RTD) in mixing reactors. The economic benefits of using radiotracer in these applications are significant. However, research work shall be conducted to develop the techniques as well as engineering the operation equipment to be suitable for harsh environments in the chemical processes. This paper discusses the preliminary work at TINT in attempt to develop radiotracer technique for leak rate detection. An available experimental setup at TINT was used for conducting the leak detection measurement. This paper provides the setup details of the experiment. The obtained measured data from the experiment were processed using the IAEA software and the result was compared with the actual measurement.

¹ To whom any correspondence should be addressed.
2. Experimental description
The existing radiotracer experimental setup at Nuclear Technology Service Centre, Thailand Institute of Nuclear Technology (TINT) had been used in this work for the laboratory experiment. The results obtained were compared with calculating results. The details of the experimental setup and the calculating methods are as follows.

2.1. Laboratory experiment
The experimental setup consists of three main parts: 1) the water tanks and piping system, 2) the radiotracer injection system, and 3) the liquid radiotracer. In this work, only the water tank #2 was used to simulate the leakage in the heat exchanger. A small opening valve was used to mimic the leakage of water from the primary loop to the secondary shell side of a shell and tube heat exchanger. Figure 1 shows the diagram of the experimental setup.

![Figure 1. Layout of the radiotracer laboratory setup.](image-url)
The radiotracer, Br-82 (approximately 10 mCi), in the form of NH₄Br aqueous solution was injected into the test system at the injection point as shown in Figure 2b. Three NaI detectors were placed along the pipeline to measure the radiation signals (see Figure 2a). The first two detectors were located along the straight pipe between the pump outlet and the glass flow meter to measure the flow rate of the system. The third detector was setup at the outlet pipe of the water tank #2 in order to measure the flow leakage.

2.2. Calculation method
The radiation signals attained from the experiment were further processed for the flow rate and the amount of leakage from the main flow. The flow rate was calculated by the software called RTD program version 1.0 distributed by International Atomic Energy Agency (IAEA). The ratio of the leakage to the main flow was computed from the areas under curves of the radiation signals measured by the leak detector and the detector located at the main pipe flow [2], e.g., detector #1.

3. Results and Discussion

3.1. Flow rate measurement
The glass flow meter shows approximately 5 LPM during the experiment. The pipe diameter at the measuring locations for detector #1 and #2 is about 5 cm. Therefore, the velocity of water in the pipe is approximately 4.24 cm/s.

By using the RTD program, the radiation signals from detector #1 and #2 were used as the input to the software. The program calculated the mean residence time between the two detectors, tau or $\tau$, as 15.29 s. The two detectors were located 100 cm apart, so the velocity of the water in the pipe is about 6.54 cm/s. Besides the optimal mean resident time, tau, the RTD program also provided the optimal value of the Peclet number, Pe, which is the ratio of the advective transport rate to the diffusive transport rate of the flow. Figure 3 shows the calculation results of $\tau$ and Pe by the RTD program.
It is found that the difference of the flow rate obtained from the glass flow meter and that from the RTD program is about 54%. This discrepancy might be a result of the coarse scale of the glass flow meter and the fluctuation of the flow during the experimental time. Since the flow rate in the experiment is quite low, only a slight deviation of the value read from the flow meter can cause a high percentage difference compared to the flow rate itself. For example, if the actual flow rate is 7 LPM, but 5 LPM was read from the flow meter (due to coarse meter scale), in this case, it is approximately 29% error. If the flow rate is 7 LPM, the pipe flow velocity is around 5.94 cm, which is only 10% discrepancy from what computed by the RTD program. Therefore, to lessen this discrepancy, more accurate/finer scale flow meter and/or higher operating flow is needed for the experiments. However, if high discrepancy still exists even though more accurate flow meter is applied, mathematical model in the RTD program used in this case may not be suitable for the flow field of interest.

3.2. Leakage measurement

Before injecting the radiotracer into the system, the leak rate was measured and compared to the main flow rate. It is found that the leakage is about 0.5% of the main flow.

By using numerical integration (Trapezoidal rule), it is found that the areas under curve of the radiation signal of the main flow (detector #1, D01) and that of the leakage (detector #3, D03) are 20671.7 and 1696.3, respectively. This leads to the leakage of about 8% of the main flow. Figure 4 illustrates the main flow and leakage signals.
Figure 4: Radiation signal from the main flow detector #1(D01) and the leak detector #3(D03).

It can be seen that the leakage computed from the ratio of area under curves of the radiation signal measured from the leakage to that from the main flow are around 16 times more than the direct measurement of the leak itself. This large difference may be the result of the size difference of the measuring pipes. The sizes of the leakage and the main pipes are different which may affect the measuring efficiency of the detectors. Moreover, due to the geometry of the setup, there can be a significant accumulation of the radiotracer at the reducing pipe for the leakage loop. This may lead to higher radiotracer detected over time which may cause misinterpretation for higher leakage than reality.

To further investigate the cause of this large discrepancy, it was hypothesized that the accumulation of the radiotracer in the experiment setup was the major contributor. To test this hypothesis, first, the noise is filtered out from the signals of interest with the median filtering technique. Then, the effect of radiotracer accumulation at the leakage measurement point (signal from D03) is analyzed. The long tail of the leak signal reveals the possibility of radiotracer accumulation at the leak setup. If there were no radiotracer build-up at the pipe reducer, the peak of the leak signal should be almost symmetry similar to that of the signal obtained from the main flow (D01). If we consider only the area under peak for the main flow and assuming symmetry shape for the leak signal, peak areas are 19771 and 554 for the main flow and for the leakage, respectively. The percentage leakage in this case is approximately 2.8 which is about 5.6 times larger than the result from the direct measurement. The filtered signals are shown in Figure 5.
Figure 5: Filtered signals from the main flow detector #1(D01) and the leak detector #3(D03).

When comparing to the discrepancy of 16 times in the previous result, this analysis shows that, without the accumulation in the experiment setup, the measured leakage is more accurate. The analysis encourages the possibility of the hypothesis that radiotracer accumulation at the leakage measurement point is one cause for the discrepancy of the results from the radiotracer method and the direct measurement. Future experiments will be performed to identify other sources of discrepancies.

In order to study the factors that cause the result discrepancy in more details, the effect of the pipe size to the detector measuring efficiency should be studied. In the future, the setup for leak study should also be modified to lessen or, if possible, eliminate the radiotracer accumulation effect.

4. Conclusions
The radiotracer experiment using Br-82, in the form of NH$_4$Br aqueous solution, was performed at TINT. Two flow properties were studied in this work, i.e., flow rate and leakage from the main flow. The radiation signals were detected by three NaI detectors placed in three different locations in order to measure those flow properties. Direct measuring methods were also conducted to measure flow rate and leakage from the main flow. This information was used to compare with the results obtained by the radiotracer methodology. In this work, the velocity and percentage leakage obtained from the radiotracer method were found to be different from those measuring from the direct measurements. The plausible causes of the discrepancy are the coarse scale of the measuring equipment, the effect of pipe size on the measuring efficiency of detectors and the significant accumulation of radiotracer at the reducing pipe of the leakage control valve. If the effects of those causes can be lessen or eliminate, it is highly possible that the radiotracer method can provide a fairly consistent results with the one obtained from the direct measuring methods. In that case, the radiotracer method will be a very useful way for on-line measuring of flow properties where direct measuring method cannot be performed.

5. References
[1] International Atomic Energy Agency 2004 Radiotracer Applications in Industry - A Guidebook, Technical Reports Series 423 (Vienna: International Atomic Energy Agency)
[2] International Atomic Energy Agency 2009 Leak detection in heat exchangers and underground pipelines using radiotracers: material for education and on-the-job training for practitioners of radiotracer technology, Training course series No.38 (Vienna: International Atomic Energy Agency)