A study of residence time distribution in a lab scale stirred tank reactor using radiotracer technique

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Abstract. The mixing characteristic of a chemical reactor can be studied through the resident time distribution (RTD) of the reactor. One major application of the RTD is to perform troubleshooting for a reactor in operation. The deviations from ideal mixing condition such as presence of stagnant region, bypassing of fluids in the system, blockage or failure of the devices in the reactor can be observed through its RTD. In this paper, the study of RTD in a lab scale stirred tank reactor using radiotracer technique is presented. A small scale stirred tank reactor is used to represent a reactor in industry. The objective of this work is to gain experience on the handling of RTD measurement using radiotracer as well as performing RTD analysis of stirred tank reactor with different flow conditions. Tc-99m solution is selected to be used in this work due to its chemical property, its suitable half-life and its on-site availability. NaI detectors were placed along the pipelines in order to determine the RTD of the system. The RTD and the Mean Residence Time (MRT) of the reactor is calculated and analysed for the case of normal flow condition and the system with some blockages.

1. Introduction

A stirred tank reactor is typical components in various industrial facilities. The mixing in a stirred tank reactor is often not ideal which the theoretical model may not be applicable to explain its behaviour. When physical change occurs inside of the reactor, reducing system performance, it is even more difficult to identify the problem while the system is still in operation. The radiotracer technique is competitive with other inspection methods in troubleshooting inspection and process analysis of such systems due to its sensitivity and ability to be performed as the process is in operation [3]. Residence Time Distribution (RTD) and the mean residence time (MRT) are parameters relevant to the performance of chemical reactors which can be used to help identify deviation of the system performance from its baseline condition. Together with the advantages of using radiotracer technique as the online investigation tools, the analyzing of the system RTD maybe help to troubleshooting the system before the severe failure of the whole system arises. This paper aims to obtain the knowledge and experience on the RTD analysis of different flow conditions through the lab-scaled stirred tank reactor. The paper discusses the experiment conducted at the radiotracer laboratory, Thailand Institute of Nuclear Technology (TINT). The following sections provides the setup details of the experiment, the results from the experiment, and the RTD and MRT analysis of the systems.

2. Experimental Description

The experiment was carried out at the radiotracer laboratory, Thailand Institute of Nuclear Technology (Public Organization), Thailand. The whole radiotracer testing system was designed to represent a
simple system of an actual industrial plant. The system consists of water supply tanks, a stirred tank reactor, a heat exchanger unit, radioactive material decay tank and a piping system. The measured radiation signals from the experiment were then processed for the system RTD and MRT. The results were further analysed to identify the difference of the system conditions, i.e., normal and blockage condition. The experimental setup and the calculation methods are described below.

2.1. Experimental Setup
The experimental setup at the radiotracer laboratory consists of 4 main components: 1) water supply tanks, 2) heat exchanger unit; 3) stirred tank reactor, and 4) radioactive material decay tanks. The layout and the pictures of the experimental setup are shown in Figure 1 to Figure 3.

Figure 1. Experimental setup diagram at the radiotracer laboratory, Thailand Institute of Nuclear Technology (Public Organization), Nakhon Nayok, Thailand.
The radiotracer, Tc-99m solution, was injected into the system at the injection point as shown in Figure 4. Six NaI detectors were placed along the pipeline to measure the radiation signals (see Figure 4). Two different setups were arranged for the detectors at the inlet and outlet of the reactor tank, i.e., normal collimator and normal collimator with extra lead shielding, in order to investigate the effect of surrounded radiation on the measured data during the experiment. The first detector was located close to the injection point to ensure the injection of the radiotracer into the test system. The second and third detectors were placed at the inlet of the stirred tank reactor as redundancy to measure signals of the radiotracer at the inlet. The other three detectors were set, as redundancy system, at the outlet of the reactor tank for the RTD measurement as the radiotracer leaving the reactor.
Two experimental cases were conducted to study RTD and MRT of the radiotracer for different flow conditions inside of the stirred tank reactor. The first experiment was performed for the normal operation condition of the reactor without any blockage inside of the reactor tank. This can be used as the baseline data for the reactor. The second case was carried out with an approximately 18% blockage of the flow area inside of the tank. In this case, a thick rubber sheet was installed inside of the reactor to obstruct the water flow (See Figure 5). This experiment can be used to mimic the case where some blockages occur inside of the chemical reactor in an actual industrial plant.

2.2. Calculation method

The RTD and MRT of the stirred tank reactor were computed from the radiation signals obtained from the experiments by the following equations [1], [2]

\[ RTD = E(t) = \frac{n_c(t)}{\int_0^\infty n_c(t)dt} \]

\[ MRT = \int_0^\infty tE(t)dt \]

where \( n_c(t) \) is the count rate attained from the measurements.

3. Results and Discussion

The radiation signals obtained from all detectors for the baseline case were shown in Figure 6. It can be seen that the inlet signals obtained from the detector #2 and #3 increased and then decreased rapidly as the radiotracer moved pass their detection points. This show that the radiotracer was injected as a pulse signal into the system. The radiation background level of the detector #3, however, was higher than that of the detector #2 due to its setup condition (no extra lead shielding). The signal obtained from the detector #3 was influenced more by the surrounded radiation, especially from the radiotracer leftover at the injection points. Therefore, if the injection point is close to the detection point of interest, it is recommended to add extra shielding for the detector in order to block out the noise radiation to obtain the better signal result.

The signals from detector #4, #5, and #6, which were measured at the outlet of the reactor, can be used to calculate the RTD and MRT of the system. As these detection points were far from the injection area, it seemed that extra shielding did not add any advantages to the signal in this case. The measured
signals showed similar behaviour for the three detectors at the outlet location. In this study the signal from detector#2 (inlet signal) and from detector#5 (outlet signal) were selected to proceed for the RTD and MRT analysis. The inlet and outlet signals for the normal flow condition were shown in Figure 7. The MRT for the baseline condition (case 1) was approximately 5.5 minute.

One technical problem found in this experiment was a significant amount of radiotracer residual at the valve of the injection point. This can be observed from the signal of the detector #1 where the signal level dropped drastically during the injection time (See Figure 6 at time ~125-175 s). After the injection, the signal from detector #1 continuously increased possibly due to the effect of radiotracer residual collecting at the injection valve. The signal then approached approximately constant level throughout the experimental period. This result suggests that improvement of the injection system shall be done for better performance and safer working condition for the radiotracer work in the future.

![Figure 6](image)

**Figure 6.** Radiation signals from six NaI detectors for the baseline condition experiment

For case 2, where some blockages presented inside the reactor, the measured signals from the six detectors showed similar behavior as that of the baseline case except the radiotracer spent more time...
inside of the reactor tank causing the longer signal tail at the outlet detection points. The processed inlet and outlet signals for case 2 were shown in Figure 8. The MRT of the system in this case was approximately 8.9 minute.

![Figure 8](image)

**Figure 8.** Inlet and outlet signals in linear scales for reactor with 18% blockage condition (case 2).

When comparing the RTD curves of both cases, it can be seen that when the blockage was presented in the system, the shape of the RTD changed from the baseline condition. The radiotracer, as well as the fluid particle in the system, spent more time in the reactor causing the tail of the RTD curve to extend longer than the normal flow condition. This caused the MRT of the system with blockage to be greater than that of the one without the obstacle in the system. Figure 9 illustrated the RTD curves of both experimental cases.

![Figure 9](image)

**Figure 9.** Comparing RTD between normal flow condition and 18% blockage condition
4. Conclusions

The Residence Time Distribution (RTD) of the lab-scale stirred tank reactor was studied for different flow conditions in attempt to understand how the RTD can be used to help troubleshooting for the reactor system in industry. The experiment was performed at the radiotracer laboratory at TINT using Tc-99m solution as the radiotracer. The RTD and MRT results for the two different operating conditions (normal flow and 18% blockage condition) performed in this study showed consistency trends with the theoretical expectation, i.e., physical change of the flow channel will affect the RTD and MRT of the system. When an obstacle or blockage is presented in the system, the fluid travel time through the system increased causing longer RTD tail and larger MRT value as can be seen from the MRT results of this study. The MRT of the case with flow blockage was about 8.9 minutes while it is only 5.5 minutes for the normal flow condition. The results from this study support the idea of using radiotracer technique to produce the RTD profile which, after analysing, can then be helped to identify physical change of a system that may cause performance reduction in industrial plant facilities.

References

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