

# Application of Smart Radiotracer Data Analysis (SRDA) Software for Industrial Application

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**Abstract.** Radiotracers technique uses a radioactive source and scintillation detectors to accurately detect plant production anomalies and mechanical damage in the plant. The greatest benefit of radiotracer technology over the conventional methods is that the investigation can be carried out on-stream and without disrupting the operating process of the plant. The residence time distribution (RTD) is one of the important parameters that provide hydrodynamics of the reactor as well as process plant anomalies. Nevertheless, the data is obtained through multichannel analyzer and the analysis of RTD is carried out later and not on site. This is because the lengthy data treatments should be conducted to the counts before obtaining the RTD curve. This data treatment process is cumbersome and time consuming. Thus, this proposal is to describe the application of developed smart radiotracer data analysis (SRDA) software by Nuclear Malaysia so that it can accelerate industrial analysis. In this study, RTD in mixing process has been carried out using SRDA and instant result such as percentage of dead zone has been determined and optimized. The optimized parameters for mixing process are 100 rpm speed of impeller, clearance of 100mm and  $U_{tip}$  is 0.5m/s which result in 1.1% dead zone.

## 1. Introduction

Radiotracer technology (RT) has helped industries in the process optimization, improvement of yield and increase the process efficiency by identifying the mechanical problems and process irregularities in their respective plants. Although RT has been widely used for past 50 years, its credibility is remained unimpeded. The most significant and salient benefit of RT is the ability to be conducted without shutting down the plant and no interruption to the operating process, which is the most concern to the plant owner. Although scheduled shut down is compulsory for maintenance, the unnecessary shutdown of plant is not welcomed since the cost is high. RT is widely used globally in oil and gas as well as petrochemical industries, waste water treatment plant industries, mineral and mining processing plant industries. In this paper, the acquisition of data from radiotracer analysis is highlighted. Previously, the signals, which derived from radioactive signals (photons) are converted to electrical signal using photo multiplier tube (PMTs) when radiation strikes the scintillator in the NaI detector. The signals, in term of counts per second (cps) are recorded in the desktop and uploaded in Microsoft Excel or .dat file. Residence Time Distribution (RTD) is one of the most important parameter in chemical engineering and process. RTD is used to assess the hydrodynamics of the process and the behaviour of the flow field as well as process plant anomalies through RTD models. It also describes how long the particle stays inside the respective unit operations [1,2]. Nevertheless, in order to analyse RTD from the recorded raw data, it has to undergo several data treatment as describe in the next part. This is to ensure that only radioactive data is diagnosed in order to simulate the RTD model so that the actual reactor behaviour or process can be described well. In order to do so, the experimental data is plotted as cps vs time prior transforming to  $E(t)$  curve by using appropriate equations as described in the Research Methodology Section (2.0). Besides, Mean Residence Time (MRT) is also calculated in order to quantify the deviation of experimental model with the ideal model and identify the type of plant anomalies such as the presence of dead zone, stagnant zone or channelling and short-circuiting. The aforementioned steps are cumbersome, step by step and time



consuming. Thus, Plant assessment Technology Group (PAT) has developed Smart Radiotracer Data Analysis Software (SRDA) to accelerate the plant diagnostic and troubleshooting. The objectives of the paper are to develop the on-line data acquisition monitoring for industrial application as well as to model the RTD for investigations of process plant behaviour.

Radiotracer Technology (RT) is using radioactive source, particularly gamma emitting source for industrial application. This is because, high energy is required to penetrate the thick and solid vessel in the plant for plant diagnostic and troubleshooting. Radiotracer technology is the only technique which utilizes small scale tracing injection in the system and yet able to provide significant and comprehensive information and flow field inside the vessel or reactor under study [3,4]. It is also the most trusted technology in providing correct information such as plant anomalies and mechanical failures of the opaque operating system or vessel. RTD study has been developed by Danckwerts (1953) and have been implemented by numerous researchers to identify possible malfunctions, pipe leakages, dead zone, mitigations and blockages in side pipelines as well as to estimate mixing homogeneity [5]. Besides RTD, RT is also used to measure the flow rates of liquid or gas as well as to calibrate the flow meter, verify leakage inside the heat exchanger system as well as to tracer the connectivity between injection well and production well in the oilfield application [6,7]. RT has the capability which outsmart conventional techniques such as in-situ detection, higher detection sensitivity, prompt respond, higher accuracy and reliability as well as availability and easy access of radioactive source especially Nuclear Malaysia has its own research reactor (RR) to produce radiotracer for industrial application [8,9,10].

International Atomic Energy Agency (IAEA) has established and recommended RTD software for the usage of its member states. Six models have been recommended to characterize the RTD model derived from radioactive based experiments. The RTD model will be fitted into the experimental RTD curve and the most optimized model is chosen based upon minimum value of Root Mean square (RMS) [2]. Figure 1 shows the fundamentals of a tracer experimental setup as described by Furman et al. (2011) [11]. There are at least two scintillation sodium iodide (NaI) detectors used for RTD investigation which are installed at the inlet and the outlet of the reactor or vessel respectively. The inlet detector is used to ensure that the tracer is entering the system correctly whereas the second detector is to record the gathered information inside the system. The peaks describe the transmitted radiation is received by the detector accordingly.

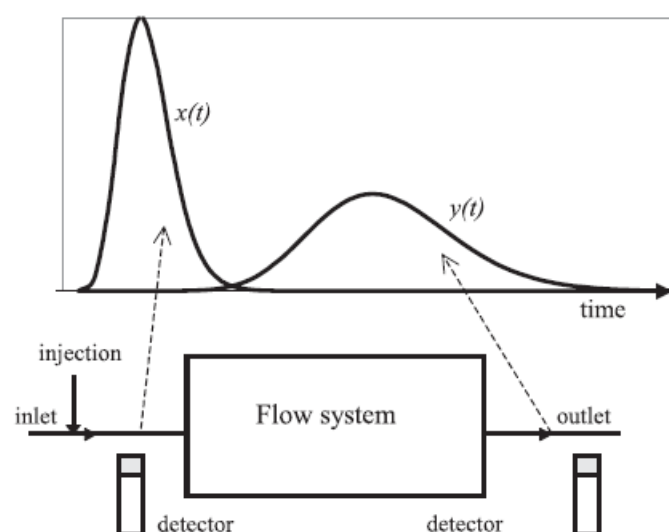


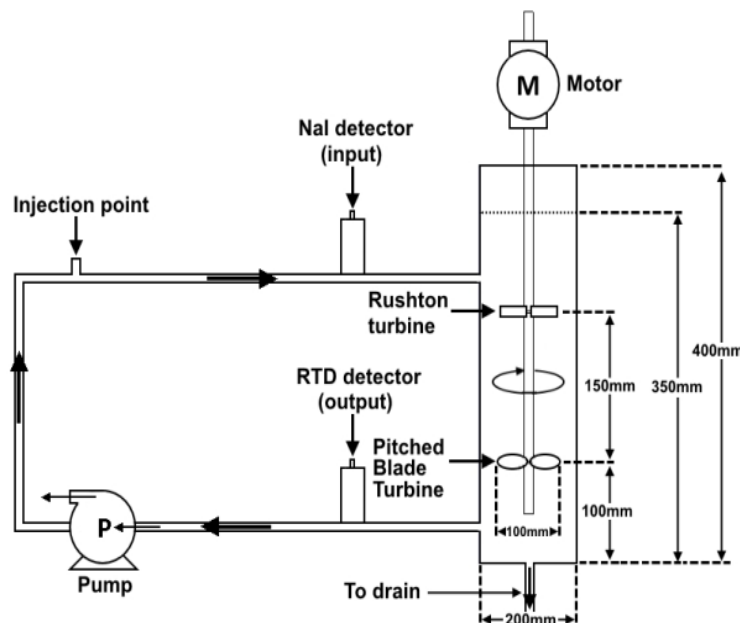
Figure 1. The principle of radiotracer experiment by Furman et al. 2011

The RTD curve of a radiotracer experiment is considered measurable after treatment of the raw data. The treatment of the data involves background correction, radioactive decay correction, starting point correction, filtering, and data extrapolation [12]. Besides, RTD is a fundamental parameter in reactor design because it can provide information on how long the substrate has been in the reactor and it can help characterise the extent of the deviation in the reactor behaviour from ideal. Besides, RTD can potentially be used to compare two different equipment designs and operating conditions. At present, the data is obtained through multichannel analyzer and the analysis of RTD and MRT are carried out later and not on site. This is because the lengthy data treatments should be conducted to the radiotracer counts before obtaining the RTD curve. Moreira et al. (2007) used DTSpro Software for that purpose which enable the preliminary of radiotracer experiment [13]. Nevertheless, prior to do that the toggle should be used in the personal computer and since the establishment was done in year 2000, the toggle is considered obsolete and not compatible with most new data acquisition system. Another option for data treatment software for radiotracer application was developed by Czech Technical University of Prague (1996). The software is not user friendly, complicated and MS DOS based [2]. Thus, this paper is to embark with the new development of smart radiotracer analysis so that it can be further utilized and accelerate any industrial applications analysis.

## 2. Methodology

### 2.1. Data treatment

Figure 2 shows the radiotracer experimental setup where the sodium iodide (NaI) scintillation detectors are located at the inlet and outlet of the mixing tank respectively. These detectors are connected to Data Acquisition System (DAS) that attached to PC for data tracking and monitoring. Water with flow rate of 5 litre per minute (5lpm) is pumped throughout the mixer to ensure that continuous flow is achieved. The initial parameters are set with 100 rpm, clearance of impeller to floor is 100 mm and  $U_{tip}$  is 0.5m/s. The  $^{99m}\text{Tc}$  radiotracer is injected once the stability of flow is achieved and the parameters have set beforehand.  $^{99m}\text{Tc}$  is eluted from molybdenum generator and emits gamma rays with energy of 0.104MeV and half-life of 6 hours. The data plotted in the graph shows the ability of NaI detectors to detect emitted gamma rays (radioactive signals) from  $^{99m}\text{Tc}$ . Nevertheless, the radioactive signals should be treated and the parasitic interference should be removed from the raw data.



**Figure 2.** Schematic diagram of mixing vessel rig for radiotracer experimentation

Therefore, LabView and Matlab application have been used to develop Smart Radiotracer Data Analysis (SRDA). The purpose is to eliminate the noises and obtain the actual radioactive representation. The treatment involves background correction, radioactive decay correction, starting point correction, filtering, and data extrapolation. All these treatments should be carried out prior Residence Time Distribution (RTD) determination. The steps of data treatment are as follows:

1. Background correction: This step is used to remove the existing background radiation

$$C_c = C_m - B_r \quad (1)$$

where  $C_c$  is the corrected radiotracer concentration,  $C_m$  is the measured radiotracer concentration, and  $B_r$  is the background radiation level.

2. Radioactive decay correction: Use the following equation to compensate for this decay:

$$C_r(t) = C_m(t)e^{\lambda t} \quad (2)$$

where  $C_m(t)$  is the measured concentration as a function of time,  $C_r(t)$  is the real concentration as a function of time, and  $\lambda$  is called the decay constant, and it is represented by the following equation:

$$\lambda = \ln(2)/t^{1/2} \quad (3)$$

3. Starting point correction: This step is used to make the starting point equal to zero to remove any counts before the injection.

4. Filtering: This step is used to eliminate the fluctuations resulting from counting statistical noise or electronic noise. *Cftool* from *Matlab* is used for filtering and smoothing purposes.

5. Extrapolation: This step is required to make the tracer concentration rates go back to zero after the end of the data acquisition. This step can be performed with the following equation:

$$C_e(t) = C(t)e^{-t} \quad (4)$$

## 2.2. Residence Time Distribution and Mean Residence Time (MRT)

In order to assess the mixing process operation and condition, the estimation of residence time distribution (RTD) is carried out. This parameter is enabled to identify the type of process anomalies such as presence of dead zone, stagnant zone as well as channelling and short-circuiting inside the mixing column. Hence, the treated data will undergo data transformation in which the following equation should be applied:

$$E(t) = C_i(t) / \int_0^\infty C(t) dt \quad (5)$$

The curve obtained is the RTD curve which represent the hydrodynamics of liquid behavior as well as the time taken of radiotracer in the reactor and the plotted graph is  $E(t)$  vs time (s). The MRT is the averaged data of RTD and is used to estimate or detect quantitatively the percentage of dead zone, channelling or fouling present in the reactor. The data from RTD will be transformed into MRT using following formula:

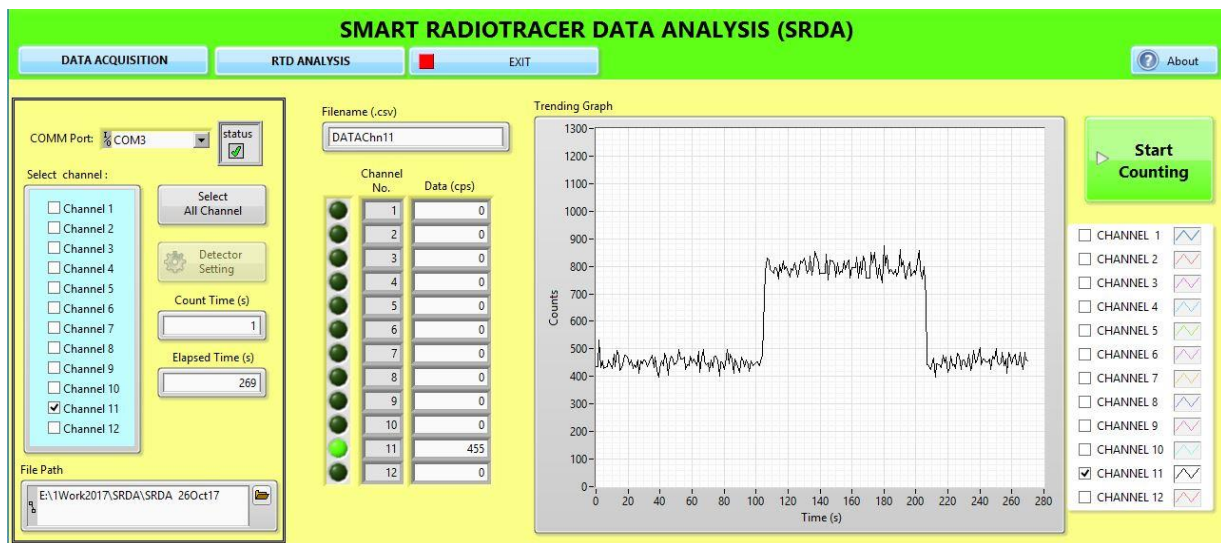
$$\tau = \int_0^\infty tE(t) dt \quad (6)$$

Therefore, SRDA will substitute the former technique in acquiring and analyzing radiotracer data in simple and quick manner.

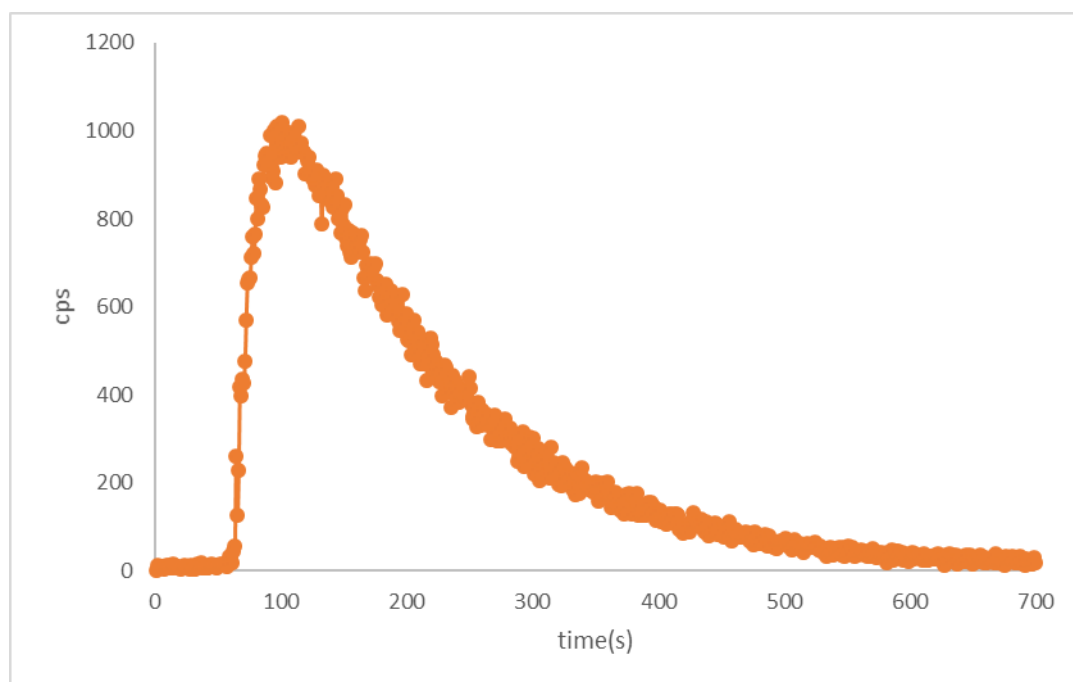
## 3. Results and Discussions

Figure 3 shows the GUI of developed SRDA which comprises of data acquisition of radioisotopes ( $^{99m}\text{Tc}$ ) which can be monitored online and RTD Analysis. The beauty of this developed software is, it can convert the raw data curve from experiment into well –curve treated data automatically. Figure 4

shows the actual plot of raw data prior data treatment is carried out. It can be observed clearly that the signal to noise ratio (SNR) is higher which influence the actual radioactive signal emitted from  $^{99m}\text{Tc}$ .

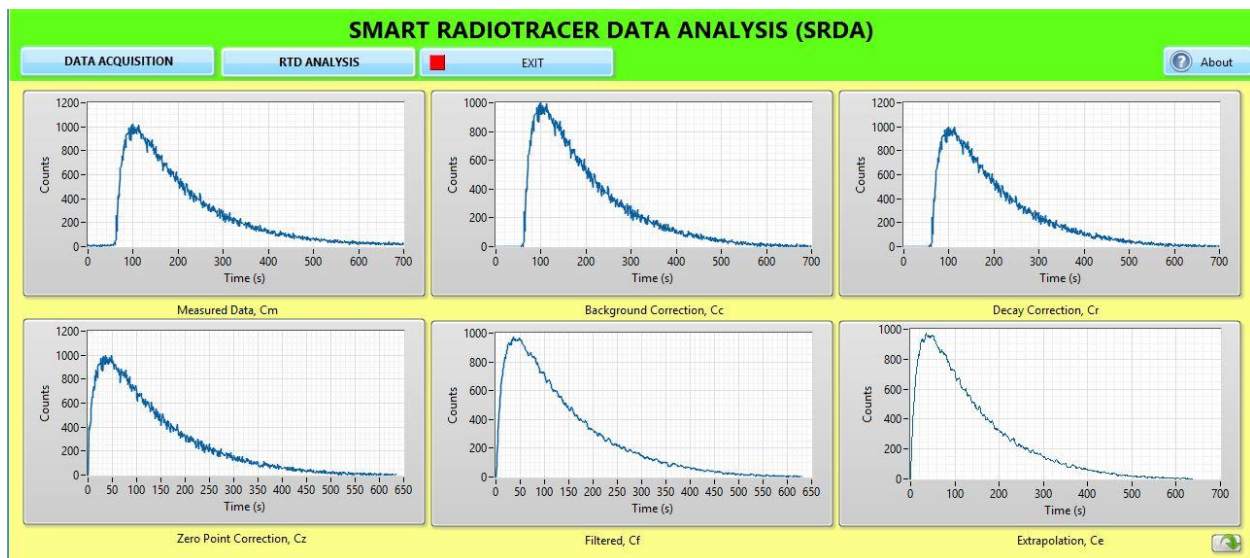


**Figure 3.** Online monitoring after radioactive injection into the system



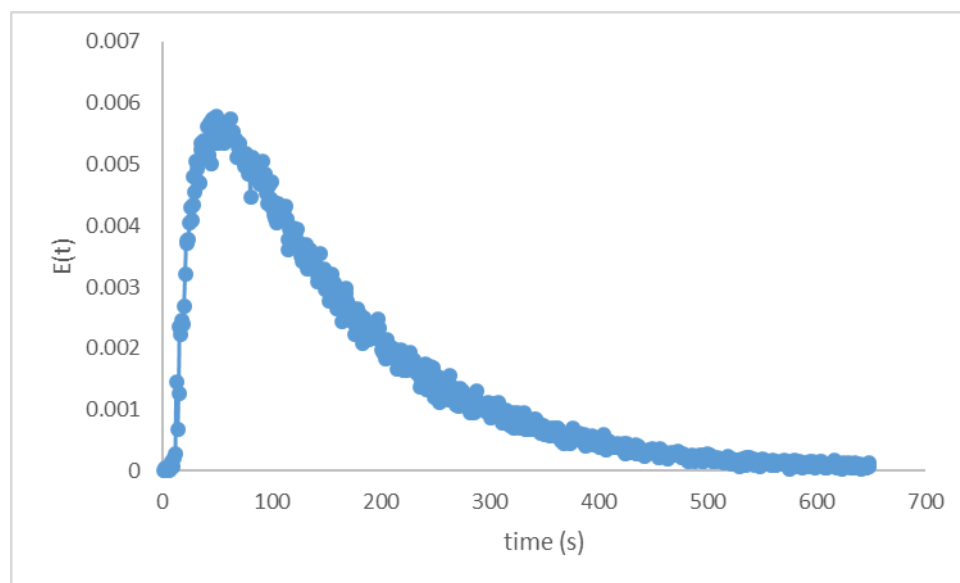
**Figure 4.** Plotted graph of raw data

By undergoing all data treatment steps as aforementioned, the step by step data treatment can be seen in Figure 5. Unlike conventional practice that is time consuming in which each of the data treatment should be calculated manually as described in Equations 1-6. It can be observed that parasitic noises are very imminent in the first measured data, and the treatments are followed consecutively from background correction, decay correction, zero point correction, filtered data and extrapolation respectively in order to obtain radioactive signals which are further developed for RTD analysis.



**Figure 5.** Automatic data treatment analysis

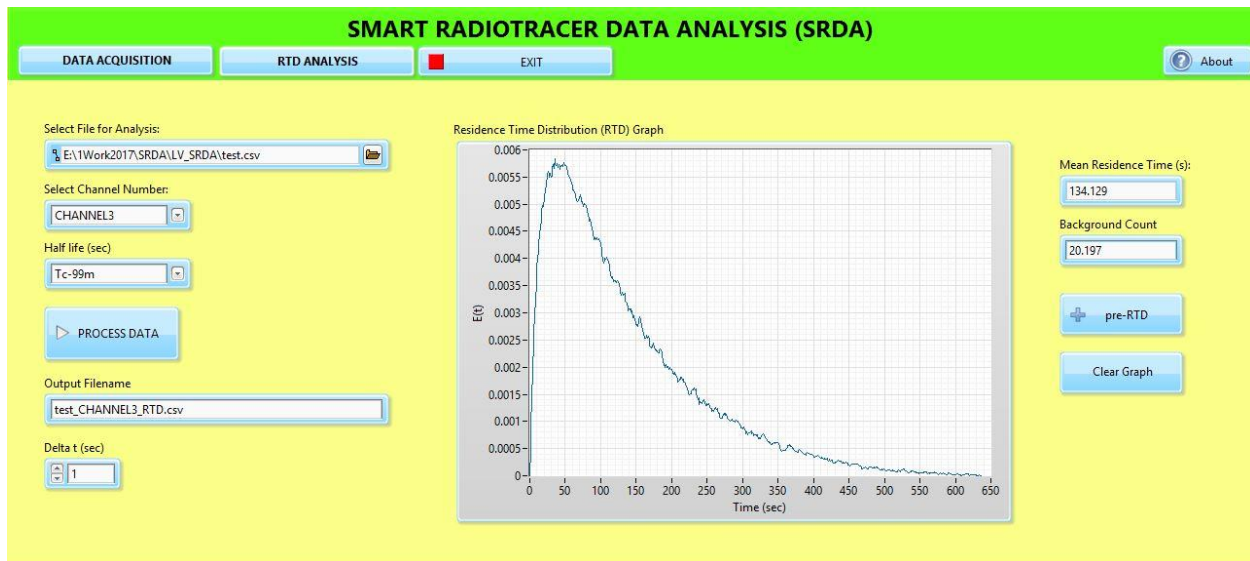
The final data treatment step, which is extrapolation has produced treated data that free from noises and can represent radioactive data accurately and precisely. The final counts (cps) vs time curve is then undergoing another analysis for determination of RTD which adopts Equation 5.



**Figure 6.** RTD determination using Eq. 5

Figure 6 shows the manually plotted curve of RTD and the value of MRT using Equation 6 is 133.60 s whereas Figure 7 provides the hassle free RTD curve and automatic calculated MRT which is 134s.





**Figure 7.** RTD Measurement and MRT Determination

Nevertheless, in order to determine quantitatively the percentage of dead zone or stagnant zone in the processing mixer column, the calculation of theoretical MRT should be carried out and the equation is as follows:

The theoretical MRT is the ratio of the vessel volume,  $V$ , to the volumetric flow rate,  $Q$ :

$$MRT_{theory} = \frac{V}{Q} \quad (7)$$

The measured value of active volume,  $V$  by adopting  $\pi r^2 h$  is 0.011m<sup>3</sup> or 11L where  $r=d/2$ ; 200mm/2 and  $h=350$ mm. The volumetric flow rate is 5 l/m or 0.083l/s. Therefore, theoretical MRT for this study is 132.5s. Thus, the relative difference between theoretical and experimental residence time or dead zone is:

$$V_{dead} (\%) = \frac{MRT_{theory} - \tau}{MRT_{theory}} \times 100 \quad (8)$$

Hence, the percentage of dead zone in this case study is 1.1% which shows the existing parameters are sufficient to retain the process optimization

#### 4. Conclusions

The development of Smart Radiotracer Data Analysis (SRDA) as an easy, fast and simple data analysis has been using as tool in assisting radiotracer engineer especially Plant Assessment Technology group in determining process anomalies efficiently and effectively in industrial plant in Malaysia.

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