Residence Time Distribution Measurements

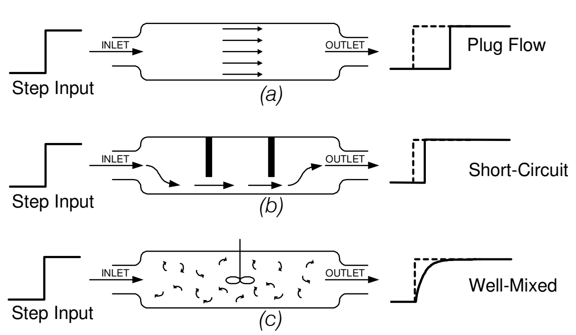
Coanda Technical Note 5.0

Residence time distribution (RTD) measurements provide an effective technique to diagnose flow behaviour within a wide range of flow systems. RTD analysis of a controlled tracer addition into a system can reveal flow distribution characteristics such as transit times, short-circuiting, re-circulation zones, and dead zones. The system under study can range from reactants flowing through a process vessel to bio-agents dispersing through a building. RTD methods may also be used to develop and validate flow models, and can be applied to field and lab-scale systems from the size of millimeters to several meters representing residence times of milliseconds to hours.

RTD Technique

For a simple RTD experiment, a known tracer distribution is introduced into the inlet of a system, and the tracer concentration is recorded at the outlet after it has been modified by the system processes. Analysis of this convoluted output tracer distribution allows insight into the processes that brought those changes about. In addition to this simple case, tracer addition and detection may be performed at locations other than the system inlet and outlet, allowing for the isolation of particular flow phenomena of interest.

Several examples of system behaviours are illustrated in Figure 1. In the plug flow reactor shown in Figure 1a the inlet tracer distribution is not modified at all by the system process, and is simply convected through while maintaining its original shape. Experimental data demonstrating this effect is shown in Figure 2 where the Configuration 1 outlet RTD is identical to the inlet step RTD. If short circuiting occurs, as in the baffled reactor shown in Figure 1b, the step change moves through the system much faster than anticipated due to the non-participation of a large portion of the vessel volume. In the well-mixed system shown in Figure 1c the tracer concentration is always uniformly distributed throughout the flow volume as tracer is added and exhausted. In this case the response to a step input is an exponential rise beginning at the moment of tracer introduction.



1 – Illustration of system RTD behaviour

Application of RTD Methods

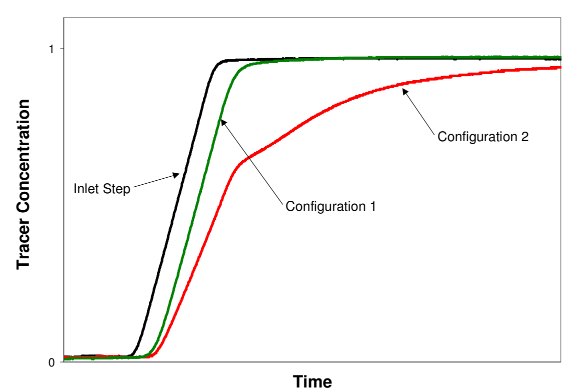
RTD applications range from the characterization of flow systems, to determining flow distribution patterns, to developing system models. These elements are combined in an integrated approach designed to address the specific needs of a particular client.

Characterization of Flow Systems

Knowledge of the type of flow behaviour occurring within a process vessel allows for verification of a system design or indication of possible design improvements. For example, the mixing characteristics within a vessel have important consequences for a range of applications with respect to heat transfer, mixing efficiency and conversion rates.

Determinination of Flow Distribution Patterns

It is possible to diagnose specific flow distribution problems by examining RTD traces. For example, the illustration in Figure 1b shows a case of short-circuiting. Portions of the flow volume are not addressed by the process stream, leading to stagnant or "dead" zones. Short circuiting is typified by a tracer transit time that is shorter than the ideal plug flow case shown in Figure 1a where transit time can be calculated using internal



2 – Experimental step-change RTD obtained from process vessel volume and volumetric flow rate. These dead zones may cause reactants to linger at specific locations for extended periods, leading to sub-optimal product yields or process performance.

Development of System Models

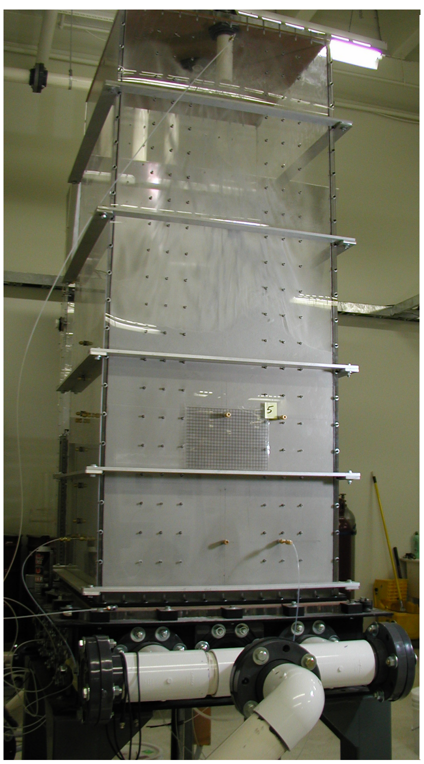
RTD curves can reveal what physical processes are occurring within the flow system, and provide a basis for developing system models. Figure 2 shows results from a step change experiment performed on a process vessel with two different internal configurations. The RTD curve for Configuration 1 shows nearly perfect plug flow, with the outlet RTD nearly identical to the original inlet tracer step. Under the same operating conditions but using Configuration 2, the outlet RTD changes drastically. By developing and evaluating phenomenological models in context with data such as that shown in Figure 2, very subtle and complex behaviours within the flow system can be captured and predicted.

Tracer Methods

Gas Tracing

Gas-tracer RTD studies have been successfully conducted on a wide range of systems at Coanda including gas-only, multiphase gas-liquid and gas-solids systems. These studies have included field and lab measurements in packed reactant beds, small-channel condensing flows, and fluidized beds such as the one pictured in Figure 3. Gas detection systems have included a photo-ionization detector, infra-red detector and thermal conductivity detector. Available tracer gases include:

- Propylene
- Propane
- Ethane
- Helium
- Hydrogen
- Carbon Dioxide



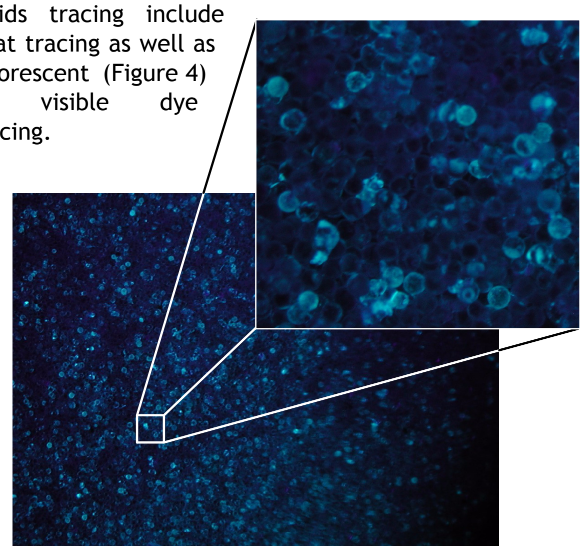
3 – Fluidized bed built and operated at Coanda (dimensions 0.75x0.75x2m)

Liquid Tracing

Coanda has well-established expertise in applying advanced liquid-tracer RTD techniques. These techniques have been applied to systems ranging from stirred tank reactors to inertial mixing and separation vessels containing liquid-only as well as liquid-solid (slurry) flows. Primary diagnostics include a laser-induced fluorescence technique. This is where a tracer of fluorescent dye solution is introduced into the liquid system and then traced using laser illumination. In addition, conductivity probes are available that use saline solution as a tracer, and are effective in obscured flows or opaque liquids.

Solids Tracing

A novel method of solids tracer addition and sampling has been developed at Coanda for performing solid-phase RTD studies in gas-solid (fluidized bed) reactors. This technique was successfully applied to the fluidized bed shown in Figure 3 Other available techniques for solids tracing include heat tracing as well as fluorescent (Figure 4) or visible dye tracing.



4 – Fluorescent-dyed particles in a background of un-dyed particles under ultraviolet illumination

Additional Information

For more information on Coanda's RTD capabilities, or any other fluid dynamic related problem please contact Coanda at the address below.

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