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# Smart RTD for multiphase flow systems

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ABSTRACT

A relatively new concept is presented for evaluation of the fluid age distribution $a = a(\mathbf{x},t)$ within the interior of an apparatus. In the standard RTD approach, the tracer study is performed and the residence time distribution is obtained. In the new approach denoted as SRTD, the fluid age is considered as the field quantity and the governing equation is formulated for its spatio-temporal distribution within the flow domain. There are only few studies devoted to this alternative approach, which typically concern only the single-phase flow systems. In this contribution we investigate its applicability also to multiphase systems. In the case of a bubble column, both the RTD and SRTD concepts are employed and discussed. The results are calculated numerically and compared with the experimental observations.



*Keywords:* Residence time; Fluid particle age; RTD; SRTD; Multiphase systems; Bubble column

## 1. Introduction

The tracer concept of RTD (residence/retention time distribution) is the standard part of the engineering education and was developed a long time ago (e.g. Danckwerts 1953, Levenspiel 1962, Froment & Bischoff, 1990, Nauman, 2008). The knowledge of RTD is useful for making a rough picture of the flow pattern inside the equipment, which is usually inaccessible to visual observations. Then, the flow structure can be described with various models dividing the domain into different zones: mixed, piston, shortcuts, dead space, circulation, etc. (e.g. Pareek et al., 2001; Claudel et al., 2003; Rigopoulos & Jones, 2003; Hocine et al., 2008; Montastruc et al., 2009). In case of a flow prevailing in one spatial dimension, like in pipes, the concept of axial dispersion is helpful, and the RTD can be linked to the solution of the 1D convection–diffusion equation, governed by the Peclet number, $\mathrm{Pe} = LU/D_{\mathrm{ax}}$, where $L$ and $U$ are the length and velocity scales and $D_{\mathrm{ax}}$ is the axial dispersion coefficient. The knowledge of RTD is also used for estimation of the conversion in the system, in case of reacting flows. The assumptions typically employed in the RTD are about the closeness/openness of the system, main features of the flow, e.g. flow steadiness, system volume and inflow constancy, etc. Other diffusion-like transport processes may be considered, e.g. gradient molecular tracer diffusion, self-diffusion of fluid molecules, turbulent flow dispersion, etc. The simplest result of the classical RTD experiment is the mean time $\theta$ spent by a fluid particle in the system and its variance $\sigma$, being the first and second moments of the $E$-function respectively. The information about the system inside is involved in the $I$-function.

The RTD is the very first thing to be determined when a chemical engineer approaches an apparatus. We must determine the transfer function of the flow system, i.e. the way how the tracer input (stimulus) is mapped onto the output (response). This information is contained in the record of the exit tracer concentration $c_e(t)$, mass-flow averaged over the exit cross section $\hat{c}_e(t)$. The tracer is assumed to be a ‘passive scalar’ that sticks to the fluid particle to mark it and to follow the streamlines of the flow field. Usually, an *experiment* with a tracer is performed where the time series of $c_e$ is measured, as a response to the tracer input in the form of a pulse or a step. Several statistical functions based on $c_e$ are used, related to the fluid particles age $a$, either at the outlet or inside the flow domain. The response $c_e(t)/C_m$ to a *single pulse* is identified with the exit age distribution $E(t)$, where $C_m$ is the mean

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