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**Keywords: Distribution, Residence time, Duration, Processing, Tracer.**

# Measuring residence time distribution
# Tracers

## 1. Introduction

This document presents the findings of TECALIMAN studies on various residence time distribution (RTD) tracers.

## 2. Tracer assessment

Table 1 lists all the tracers involved in the studies.

| Tracer | | Dosing method | Bibliographic reference |
|---|---|---|---|
| **Tracer name** | **Presentation and composition** | | |
| Proteins | Soya meal | Protein content determined by infra-red spectrophotometry | Riou Y. 1999 |
| Sodium chloride | Corn cob particles soaked in (NaCl) | NaCl content determined by conductimetry | Mabit J. 1997 |
| Fluorochrome | Corn cob particles dyed with a fluorochrome | Fluorescent particles counted by image analysis or spectrofluorimetry | Novales 1998<br>Mabit J. 1997 |
| | | Fluorescent particles counted manually under a black light source | Riou Y. 1999 |
| Manganese nitrate | Corn cob particles soaked in manganese nitrate | Manganese content determined by chemiluminescence | Mabit J. 1997 |
| Red food colouring | Corn cob or cornmeal particles dyed with a red food colouring | Tracer particle concentration determined by sieving, dyed particles counted manually or by image analysis | Mabit J. 1997 and Chapleau N. 1998 |
| Polystyrene particles | Polystyrene particles | Polystyrene particles extracted by floating, then counted manually | Chapleau N. 1998 |
| Microtracer | Coloured iron particles | Particles extracted by magnetic element, then counted manually | Smallman C. 1996 |
| | | Particles extracted by magnetic element, dosed by colorimetrics | Tecaliman 2003 |
| Lactose | Pure powdered lactose | Chemical lactose dosing | Tecaliman 1987 |

**Table 1**

The findings of the pilot workshop concerning press conditioner or soaker processes revealed five tracers that were well suited to measuring residence time distribution in a particulate environment:

- Corn cob particles dyed with a fluorochrome (rhodamine), and dosed by image analysis or manual count under a black light source.
- Corn cob or cornmeal particles dyed with a red food colouring and dosed by manual count
- Polystyrene particles dosed by manual count.
- Coloured iron particles (Microtracer), dosed by colorimetrics
- Powdered lactose - concentration in feedstuff dosed by chemical analysis in the lab.

Of these five tracers, three were found to be

suitable for use in the animal feed industry as they comprise authorised ingredients. These were coloured iron particles (Microtracer), powdered lactose, and corn cob or cornmeal particles dyed with a food colorant. The last tracer has the advantage of being a low-cost solution, which can be produced and dosed in-plant using simple means.

- **Producing tracer using dyed corn cob or cornmeal particles**

The tracer is prepared by soaking 100g of particles of a known particle-size for 24 hours in 100 ml of an aqueous solution containing a colorant dosed at 5g/l. The solution is absorbed by the particles and the excess colorant eliminated by washing under running water. The tracer is then oven dried, stirred in a vertical shaft laboratory mixer (to destroy the bonds created between the particles), and sieved to recentre the particle size.

# 3. Impact of tracer properties on RTD measurements

Several factors likely to impact on the measurement of residence time distribution were studied, i.e. tracer particle size, bulk density and colour (Riou Y. 1999):
The results showed that, while these factors had minimal effect on RTD measurements, an optimised tracer should, where possible, have a particle size similar to that of the feedstuff and be strongly coloured (red), if dosed by manual count.

# 4. Flow behaviour of each tracer

## 4.1. Pilot workshop study

Tests were carried out using three tracers: red-dyed cornmeal particles, F-microtracer and polystyrene particles. Table 2 shows their properties

| Tracers | Median diameter (micron) | Bulk density (g/l) |
|---|---|---|
| **F microtracer** | 250 | 3 125 |
| **Polystyrene particles** | 625 | 616 |
| **Coloured cornmeal particles** | 522 | 650 |

**Table 2**

The tests were carried out in a pilot conditioner fed with cornmeal with a median diameter of 671 µm.
A mass equivalent to 2,000 particles of each tracer was introduced into the mixer by pulsed injection.
The dosage of tracer particles in the samples taken at the conditioner output was counted manually.
The results of these tests demonstrated that the three tracers all showed identical flow behaviour in the conditioner. They showed no difference in terms of mean residence time and the related distribution (Table 3); their residence time distribution curves were so close as to be practically superimposed (Figure 1).

| Tracer | Red-dyed cornmeal | F-blue microtracer | Polystyrene particles |
|---|---|---|---|
| **Mean residence time in seconds** | 97.5 | 98.1 | 99.1 |
| **Variance in the distribution of particle residence times** | 725.9 | 673.1 | 835.3 |

**Table 3**

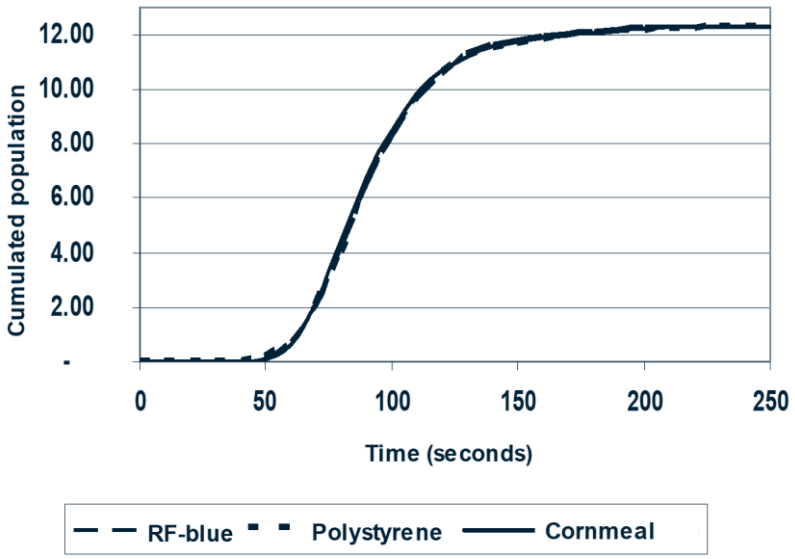


**Figure 1: Pilot press conditioner**

**RTD for various tracers injected simultaneously**

**F function (Cumulated frequency)**

## 4.2. Plant tests

The behaviour of two tracers was studied on 2 industrial lines, one comprising a press conditioner with an output rate of 5.7 t/h and the other a soaking vessel with an output rate of 10 tons/h. A mix containing a microtracer (RF-blue lake) and red-dyed corn cob particles was introduced by pulsed injection at process input. Table 4 shows their properties.

The corn cob particles were dosed by manual count; the microtracer was dosed by colorimetrics. The results demonstrated that in an industrial environment the two tracers showed virtually identical flow behaviours (Table 5, Figure 2 and Figure 3) over a broad range of residence times.

| Tracers | Median diameter (micron) | Bulk density (g/l) | Theoretical throughput time (s) |
|---|---|---|---|
| **F-blue microtracer** | 250 | 3.125 | 1.200 |
| **Corn cob particles** | 630 < d50 < 800 | 245 | 7 |

**Table 4**

| | Mean residence time (in seconds) | |
|---|---|---|
| **Tracer** | **Red-dyed corn cob particles** | **Microtracer RF-blue lake** |
| **Soaking vessel** | 1.710 | 1.712 |
| **Conditioner** | 12.6 | 13.1 |

**Table 5**

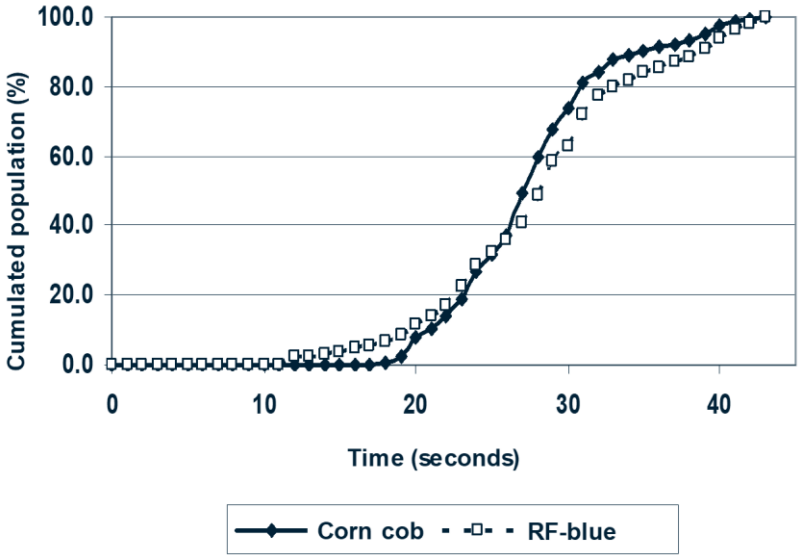


**Figure 2: Plant soaking vessel**

**RTD for various tracers injected simultaneously**

**F function (Cumulated frequency)**

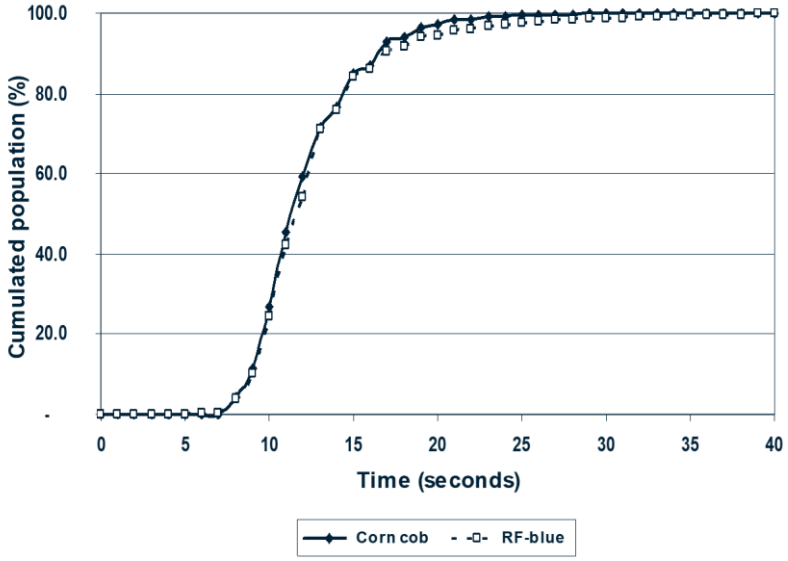


**Figure 3: Plant press conditioner**

**RTD for various tracers injected simultaneously**

**F function (Cumulated frequency)**

## 5. Bibliography

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