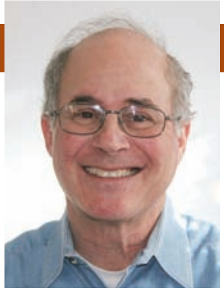

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Engineering: Residence Time Distribution IV

In my previous columns (Cereal Foods World July/August 2008, November/December 2008, and January/February 2009), I discussed the concept of a residence time distribution and described how it is measured. This column will illustrate how the residence time distribution interacts with process behavior.

One way the residence time distribution interacts with the process is when there is some kind of physical or chemical, such as a reaction, change that is rate dependent. This is easy to understand. Remember that the residence time distribution describes the probability that a particle of fluid will reside in the process for some time interval. Another way to consider the probability is as the fraction of material that resides within the process for a specified time interval. In this light, the significance of the residence time distribution is easy to see. Consider a pasteurization process in which complete pasteurization occurs in 5 min. If in passing through the process 100% of the product stays in the process for 5 min or more (probability = 100%) then all the microorganisms will be destroyed. Now consider a poorly designed process in which half of the material short circuits the process (50% probability of having a residence time of 0 min) and half stays in the process for 10 min (50% probability of having a residence time of 10 min). The average residence time of material is still 5 min, but half of the product will have no living microorganisms and half will have the original microorganism load, so the final product will have half the original microorganism load.

The concept described by this simple illustration can be generalized. If we remember that the unit pulse response, E(t), represents the probability density for a product staying in the process to a time, t, then the extent of reaction we will see is given by,

$${}^{c}\,\text{final} = \int_{0}^{\infty} c(t)\cdot E(t)\,dt$$

The rate term is usually a function of concentration, for example, a first order reaction: rate = –kc.

The rate constant, k, is in general a function of temperature, but for this discussion, we will assume that the process is isothermal (k is constant).

Let us consider three different processes with different residence time distributions. The two extremes are a well-stirred system and a plug flow system. In a well-stirred system, the distribution of residence times is random, following an exponential distribution. In a plug flow system, everything stays in the process for the same time (100% probability of material having a residence time equal to the mean residence time). As an intermediate condition, consider a process that has half its residence time as plug flow and half as a well-stirred system. Figure 1 illustrates the unit pulse response, E(t), for the three processes, all with a mean residence time of 5 min.

I won't bother the reader with the details of the integration required, but will just present results for an assumed rate constant of 0.5 min^{-1} and a total average residence time of 5 min.

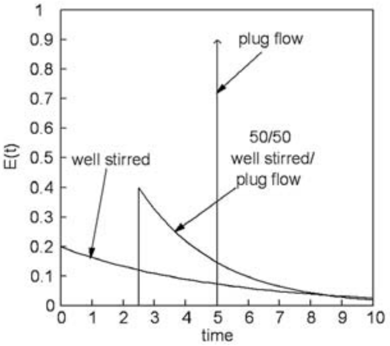

Fig. 1. Three different residence time distributions.

The results are summarized below (Table I).

The difference is obvious. There will be more than three times the number of microorganisms left after processing in a well-stirred system than after processing in a plug flow system. The system that is half and half is somewhere in between.

We can also consider a case, such as a when fermentation is taking place and microorganisms are being produced via a first order reaction: rate = kc.

For this case, assume a rate constant of 0.15 min^{-1} and a total average residence time of 5 min. We reach a different conclusion about which process is "better" (Table II).

In this case, we get a greater extent of reaction with the well-stirred system than with the plug flow system!

As the rate models get more and more complicated, for example, including reverse reactions or multiple reactions, one cannot immediately say which kind of residence time distribution is better or worse.

Table I

Process	**Fraction of Microorganisms Remaining**
Plug flow	0.082
50/50 Plug flow well stirred	0.127
Well stirred	0.286

Table II

Process	**Ratio of Final to Initial Microorganisms**
Plug flow	2.12
50/50 Plug flow well stirred	2.33
Well stirred	4

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