Recycling and the "Age" of Dough

Leon Levine
Leon Levine & Associates
Albuquerque, NM

On a number of occasions I have observed that people do not correctly consider and/or analyze the recycling of dough and other products. For the purpose of illustration, consider a simple process that incorporates recycled dough (Fig. 1). One of the things we are interested in understanding about this process is the "age" of the dough, meaning the number of times the average piece of dough has gone through the process. Why are we interested? In general, in processing a biological material, such as the simple sheeting process illustrated in Figure 1 or an extrusion process, the material irreversibly changes every time it passes through the process. In the case of the process illustrated in Figure 1, every time we pass the material through the sheeting rolls, we further "develop" the dough as a consequence of the work input of the sheeting line. Normally, sheeting a product results in a "breakdown" of the viscoelastic structure of the dough. In the case of extrusion, every time the starchy material passes through the extruder, some dextrinization of the starch occurs, or, in the case of protein-based materials, cross-linking and reduction of solubility occurs.

This kind of problem must be analyzed through the use of a non–steady state mass balance model, something that most of us never have to deal with. In fact, the analysis is quite straightforward and can be quite enlightening.

In order to simplify the analysis and alleviate the need for dealing with the fact that in the real process there is a nonuniform residence time distribution, we will make the following assumptions:

- All of the material travels through the process from the point of combination of the recycled material with the fresh material in a uniform time, τ.
- It takes no time for recycled material to go from the cutter back to the mixing point.
- The age of the dough is an additive property. That is, the age of a mixture of fresh dough and recycled dough is the weighted average of the two streams' ages. For this example, I will define age as the number of times the dough has gone through the sheeting/cutting process.

These simplifying assumptions in no way alter the general conclusions that I'm going to describe; they simply make the calculations much, much easier.

Now, let us consider a recycle rate of 50%. That is, at any instant of time, half the dough going through the process gets passed on to baking and half gets sent back to be mixed with fresh dough. The age of fresh dough is assumed to be zero. That is, it has not passed through the process. Now a little thought reveals what's going to happen.

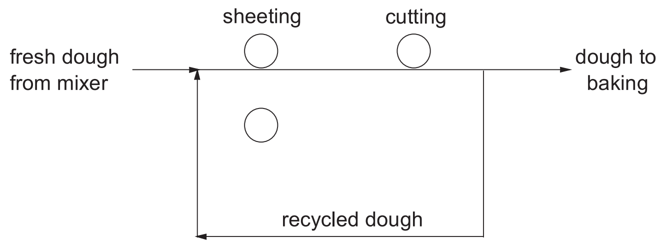

Fig. 1. A simple process that incorporates recycled dough.

No dough comes out of the process until a time period of τ has passed. After this time, dough that has been through the process once is either sent to baking or it is recycled back into the fresh dough. The age of this dough is 1 (it's gone through the process once). Because we've assumed that no time is required to bring the cut dough back to the process inlet, at time τ, the average age at the feed to the process is 0.5, because the feed is a 50/50 mixture of recycled dough (age = 1) and fresh dough (age = 0).

At τ minutes later, at time 2τ, the mixture of half fresh dough and half recycle dough exits the process. This material now has an age of 1.5 because it's made of material that entered the process at an average age of 0.5 and passed through the process, which increased it's age by 1. This material, which has an age of 1.5, is then blended 50/50 with fresh dough, and after mixing the mixture has an average age of 0.75.

At τ minutes later, at time 3τ, the mixture of half fresh dough and half recycled dough exits the process. This material now has an age of 1.75 because it's made of material that entered the process at an average age of 0.75 and passed through the process, which increased it's age by 1. This material, which has an age of 1.75, is then blended 50/50 with fresh dough, and after mixing the mixture has an average age of 0.875.

At τ minutes later, at time 4τ, the mixture of half fresh dough and half recycled dough exits the process. This material now has an age of 1.875 because it's made of material that entered the process at an average age of 0.875 and passed through the process, which increased it's age by 1. This material, which has an age of 1.875, is then blended 50/50 with fresh dough, and after mixing this mixture has an average age of 0.9375.

The process continues, ad infinitum, or until the line is shut down. I presume the reader is seeing the trend that's occurring. To summarize, see Table I.

So, if the process runs long enough, the actual age of the dough approaches 2. That is, on average, every piece of dough goes through the sheeting process twice.

The fact that the dough, at steady state, goes through the process an average of two times illustrates a mistake that's commonly encountered during the development of new products. I can't count the number of times I've seen development people, when attempting to "simulate" a commercial process, do this incorrectly.

doi:10.1094/CFW-52-6-0328

What is invariably done is that dough is sheeted once, and then it's mixed 50/50 with fresh dough, to simulate 50% recycle. This mixture, when sheeted, will only have an age of 1.5, not the age of 2, which will be encountered in the commercial operation. So, the test mixture of dough should probably be a 50/50 mixture of fresh dough and a dough that has been passed through the sheeter twice. This mixture will give an average age of 2.0 after sheeting. Alternatively, one could simply sheet the dough twice and then use that for baking.

The second thing that this example illustrates is how long it takes the process to approach steady-state operation. We have to define what steady state means, because, as Table I indicates, we never really get there. Let's take a reasonable approach to this. Let's say that if the process has experienced more than 95% of the change that will ever occur, then the process has essentially achieved steady state. As shown in Table I, it will require 6τ for the process to attain a good approximation of steady state. If a batch of dough is made every 20 minutes, then about 2 hours of line operation is required.

This is the second error that I've observed on numerous occasions. Development people go to the factory to run a new formula. It's costly to make large quantities of a new formula, so they run only 2 batches of dough down the line. Note that like the laboratory test, the average age of the dough being sent down the line is only 1.5, not the 2 that will be encountered in actual plant operation. It takes a little effort, but if one only wishes to run 2 batches of dough, then a higher recycle ratio, by adjusting the cutting operation, will be required to simulate the situation that will eventually be encountered.

The astute reader may have noticed that the data in Table I follows a geometric progression. There is a generalized formula that can be used to calculate what will happen for any arbitrary recycle rate. The expected steady-state age for various levels of recycle is given by the equation

$$\text{age} = 1/(1 - f)$$

where f is the fraction recycled.

The time progression can also be worked out. The higher the percent recycle, the greater the number of passes required to reach the approximation of steady state. For the results of the 95% approach criteria, see Table II. It's pretty obvious that one has to wait a very long time for steady process operation if high recycle ratios are used.

Table I. Age of dough assuming 50% recycle

Time after start	"Age" exiting process
τ	1
2τ	1.5
3τ	1.75
4τ	1.875
5τ	1.9375
6τ	1.95875
.	.
.	.
Infinity	2

Table II. Number of runs required to simulate steady state

Percent recycled	Number of times required
20	2
33	3
50	6
67	9
75	12
88	24

Acknowledgment
My thanks to Robert Miller for his suggestion for this column.

Leon Levine has B.S. and M.S. degrees in chemical engineering and a Ph.D. in agricultural and biological engineering. He is a consultant on food processing in other consumer-goods industries. Levine can be reached at leon.levine@prodigy.net.