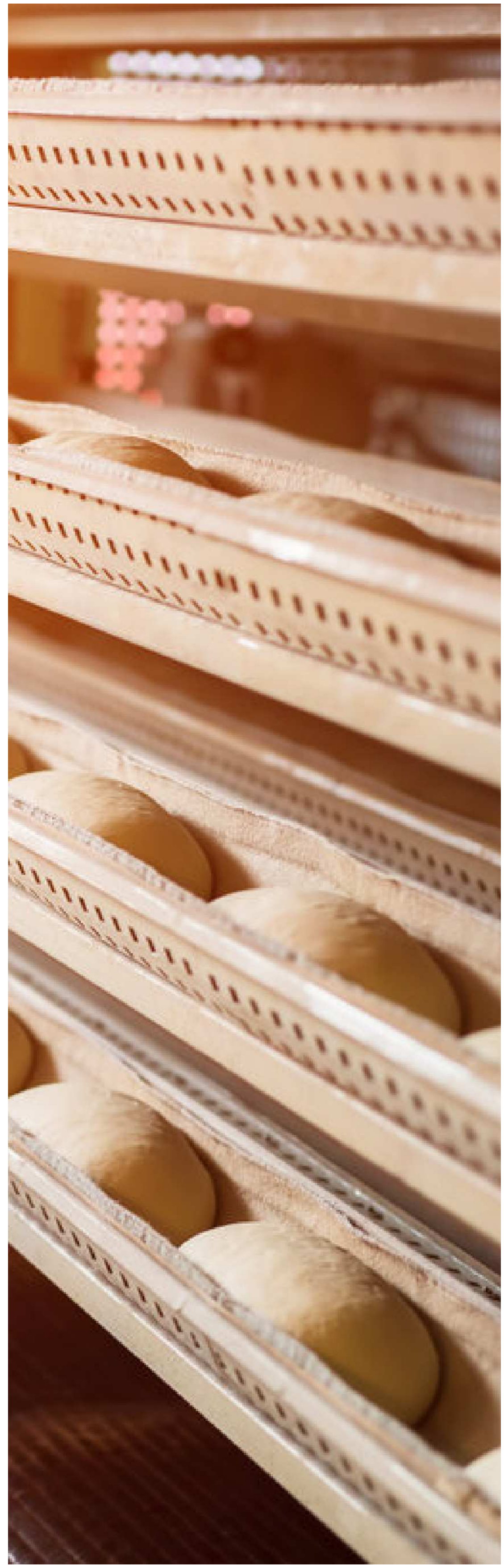
S-Curve Management: Maximize Bread Yields

How do you bake the perfect loaf? Data about dough transformation during baking is key. Tracking and managing your product's journey thorough the oven allows you to optimize your baking operation for improved results.

Monitoring internal dough temperatures during a baking cycle is a crucial element of process control to ensure consistent, repeatable quality products. Known as bread thermal profiling, dough temperatures are measured using thermocouple sensors placed at various locations inside and outside the dough.

By collecting and understanding this data, the baking step can be optimized, shelf-life improved, and plant-wide consistency ensured.

Thermal Profiling & The S-Curve



During the baking step, dough passes through three key stages. The functional properties of these steps depend on the baking time and control over the internal dough temperature throughout the process. These stages are:

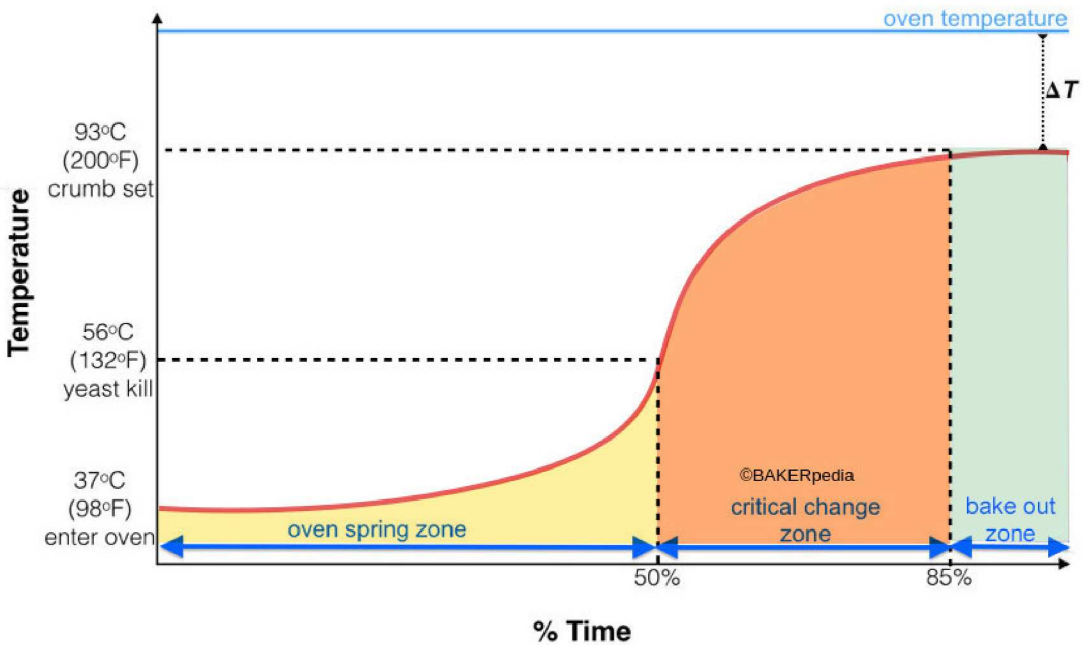
1. Yeast Kill: produces gas in the dough and raises the product volume.
2. Critical Change Zone: starch undergoes gelatinization and protein denatures, solidifying the crumb.
3. Arrival Point: product turns into a solid, and water starts escaping which impacts the final moisture content and shelf-life.

Implementing thermal profiling technology provides a log of the internal product temperature during a baking cycle and forms a graphical time-temperature representation of the baking process.

While the dough undergoes many physicochemical changes during baking, time and temperature are the most crucial, so they are considered standard control variables for bread quality.

The X-axis shows the temperature (internal product and oven temperature), and the Y-axis logs the baking time as the product passes through multiple temperature phases. This graph is commonly referred to as a S-curve.

Reading a S-Curve



In this example, the product is maintained at 37°C(98°F) for optimum fermentation output. The internal product temperature rises in the oven as it moves inside in a continuous oven system and the product passes through all three phases.

The S-curve can be read from left to right like any standard graph. The temperature axis shows internal temperatures measured by the thermocouple and the external (oven) temperatures. The oven temperatures will always be higher than the desired internal temperature. ΔT denotes the difference in the internal temperature and oven temperature.

Benchmarks for Different Baking Temps & Estimated Bake Time

	Internal Dough Temperature	Goal % of Bake Time
Yeast Kill	60°C/140°F	50 - 55%
Gelatinization	77°C/170°F	60 - 65%
Arrival (93°C/200°F)	93°C/200°F	85 - 88%

The target internal product temperature can vary in two ways compared to the achieved temperature. The entire baking process is divided into multiple zones, marked as Z1, Z2 and so on. This is represented on the X-axis. It helps to identify the specific problem zone.

Getting Accurate Data
Thermal Profiling a S-curve

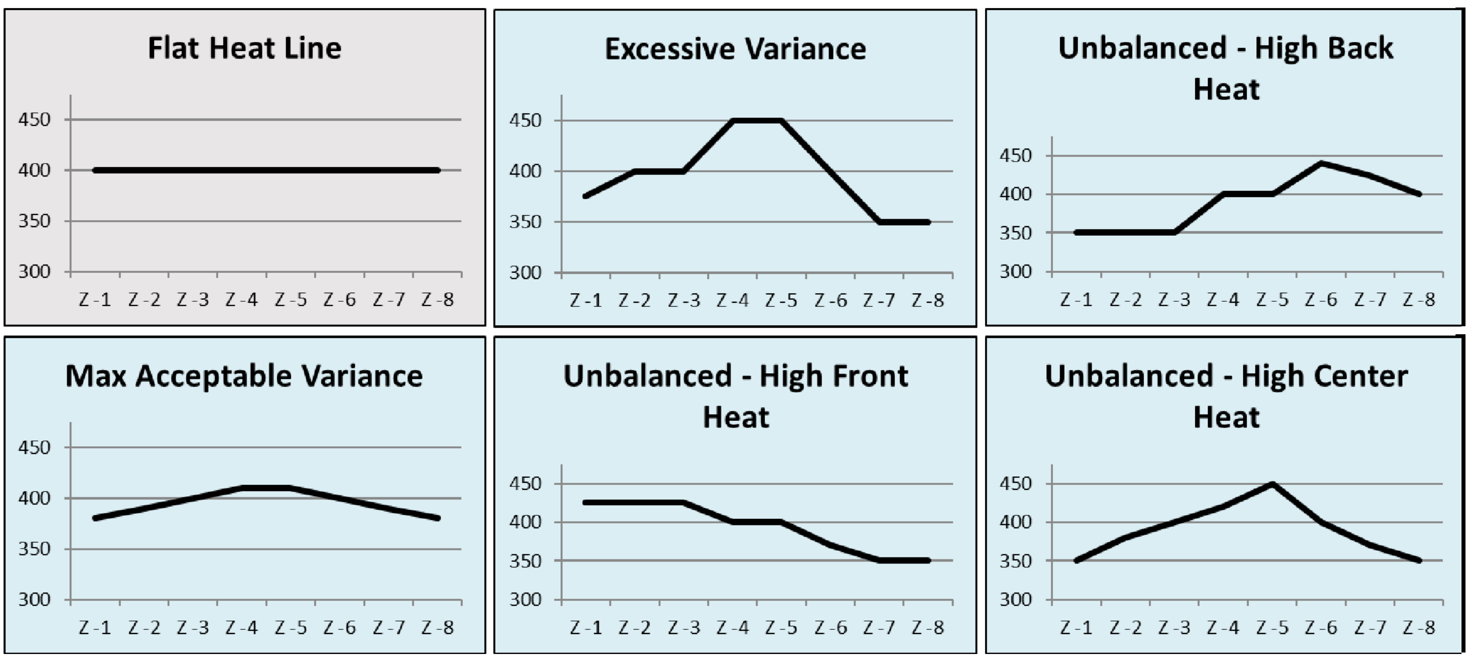
If the temperature is achieved earlier than desired, later than desired, or not at all, specific problems can arise. Here's how the baking process needs to be adjusted for specific problems. This chart illustrates how thermal proofing reduces the guesswork required to deliver analytical solutions for most baking issues:

Yeast Kill 140°F	Gelatinization 170°F	Arrival 200°F	Possibible Oven Setup or Bake Fault
Early	Early	Early	High oven temperature set points - all zones Bake time too long Low formula absorption Excessive oven BTU capacity
Early	Early	Late / None	First 65% of oven temp too high and last 35% too low First 65% of oven temp too high and bake time too short
Early	Late	Late / None	First 50% of oven temp too high and last 50% too low Short bake time with first 50% of oven temp too high
Late	Early	Early	Short bake time with first 50% of oven temp too high Long bake time with first 50% of oven temp too low Rear oven damper closed or incorrectly adjusted
Late	Late	Early	Excessive bake time with low zone temps High humidity in first 50% of oven Air drafting into oven
Late	Late	Late / None	Short bake time Low oven heat Lack of BTU avaiability Possible burner failures Cool proofer exit temps High oven humidity Air drafting into oven Exhauster imbalance on tunnel ovens

Getting Accurate Data
Thermal Profiling a S-curve (cont.)

The trendline drawn by the information from thermocouples in the graphs below can provide insight into the baking process:

- A flat heating line across various zones shows a balanced zone burner control.
- Maximum acceptable variance shows a slight bell-shaped heat line with minimal heat variation from zone to zone. It helps achieve the desired oven spring and target crust color.
- Excessive variance and unbalanced heat lines result in poor burner control and poor product bake quality. This can result in undesirable properties such as late yeast kill, low product volume, no arrival, or undesirable (very dark or very light) color due to low or high heat in the oven.



Improving Product Quality with Thermal Data Recording

Baking is a science, so a lack of tight process control can result in overbaking, a shorter shelf life and poor product texture. Thermal profiling helps reduce overbaking—which also contributes to reduced energy consumption—by monitoring the product temperatures. Reducing the bake-out time to less than 15% is the first step to avoid overbaking products.

In case of shelf-life issues, the thermal profile can be used to achieve more than 15% bake-out. The bake-out time for a gummy product needs to be increased by 3%. The bake-out zones need to be manipulated depending on the final product quality.

Ideal time duration for bake-out and arrival to achieve a soft interior without excess crumb drying:

Product	Bake-out	Arrival
Hamburger buns	18-20%	78-80%
White pan bread	15-18%	82-85%
Whole wheat bread	10-15%	85-90%
Multigrain bread	2-7%	93-98%
Rye bread	20-25%	75-80%
Sourdough bread	10-15%	85-90%

TIPS FOR ACURATE THERMAL PROFILE READINGS

To ensure data is correct, it is essential to get accurate and consistent readings with thermal profiling equipment. Sensors connected to an electronic data recorder are used on the product during baking, traveling through or rotating within the oven. Ideally, six thermocouple sensors should be used, in a combination of ambient and dough insertions. When taking a reading:

- Secure the thermocouples into the geometric center of each dough piece.
- Pinch the dough around the entrance point of each 'wire' so as not to promote excessive heat or moisture loss.
- For the ambient sensors, elbow them into and back out of the dough so the tip is at least 1" above the pan and off the edge of adjacent pans so as not to be directly above a pan, to optimize accuracy.
- Multiple runs are typically required across the oven to discern if the oven is balanced left-to-right across the conveyor, or if it's consistent between upper, mid-level, and lower shelves.

Variations in thermocouple sensor placement (i.e. location, depth, angle, etc.) and even dough placement in the oven can also cause alterations in the data. There are models available that have fixed positions for the ambient and insertion sensors up to the stop plate.

How does arrival affect quality?

The arrival point is responsible for water escaping the product after it has turned to a porous solid. High temperatures increase the rate of water evaporation leading to a dry and crumbly product. However, low temperatures reduce the rate of water evaporation leading to higher moisture content in the final product. Higher moisture leads to mold growth and, therefore, reduced shelf-life and staling. A longer bake, or earlier arrival point, would bake out the product so the bread would be more resilient.

Why do I need a thermal profile of my bread, instead of using an exit temp of 93.3°C (200°F) as a control point?

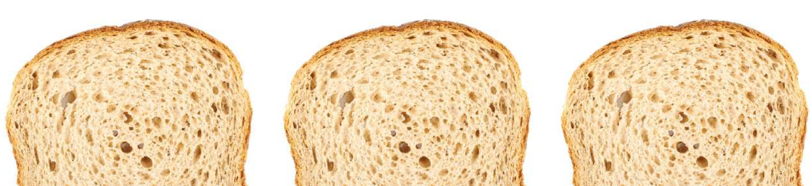
Historically, using a thermometer to determine whether bread should be taken out of the oven was industry standard. Today, with current technology, bakers can use thermal profiling as means to optimize quality. While a thermometer is a good indicator, it doesn't reveal how long the product stays in the arrival zone. The arrival zone is where the texture and color of the baked good is perfected. For example, a residence time at 15% for white bread guarantees consistency quality across shifts and changeovers.

Our sliced bread bakes well, but caves in at the sides while cooling. Why is this?

Caving (when the bread looks like a mushroom when cross cut) is the result of a vacuum effect taking place in the bread pan. This is usually seen when bread is left to cool in baking pans. Upon cooling, the air cells have an opposite effect from expansion in the oven. After cooling, while bread is still in the pan, the cooled air cells create a vacuum-like effect on the side wall, sucking it in. The best way to prevent this is to de-pan the bread immediately after it exits the oven.

What if I meet a 20% bake-out, but I do not get the color I want? Do I bake until it's golden brown?

The color in bread is primarily the result of the Maillard reaction of sugars in the dough at elevated temperatures. The light color of bread can primarily result from low sugar content, high yeast activity, and low baking time and temperatures. If thermocouples indicate a good S-curve, start by checking the yeast activity and sugar content in the formulation. Alternatively, if desired volume is achieved early in the process, incorporating an earlier yeast kill step may be required.



References & Further Reading

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